# Mineralogy & Crystallography:

## On The History Of These Sciences

## From Beginnings Through 1919

By

Curtis P. Schuh

# ( Rough Notes )

Tucson, Arizona

2007

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# Edition Note
## Internet Issue
## ( 2007 )

The files listed on the internet **do not** contain the complete and final versions of *Mineralogy & Crystallography: a Biobibliography* or the companion book, *Mineralogy & Crystallography: On the History of these Sciences*. Rather these are intermediate presentations of a portion of the computerized database being created to output a final version as printed books. However, even in this incomplete state these works give a substanial history of mineralogy and crystallography together with exhaustive descriptions of the major books. These files are being made available to the general public because of numerous requests for access to the information and the benefit to the compiler in the feedback he recieves from the readers. Although it is a work in progress with errors and formatting problems, these intermediate files are still a very useable reference sources.

The *Biobibliography* and the *History* are companion works ultimately intended to each stand complete in itself, but to never the less complement each other, with information from one feeding into the other. This is particularly true of the section labeled "Regional Histories" in the *History*, which describes the development of mineralogy in individual countries. While gathering information for the *History*, an ever increasing number of additional titles are necessarily being added to the *Biobibliography*. Happily however, there is finally an end in sight to the project. It was not possible to create the *History* without having first compiled the *Biobibliography*, and now that it is being written, work on both books is steadily drawing to a point where the text to both can be given a final edit, and be made ready for actual publication as physical books. However, in advance of that future date, these files are being placed on the internet so that researchers and scholars may reference them.

For this project, the TEX program developed by Donald Knuth professor emeritus of Stanford University has been used to format the database text and elegantly typeset the volumes directly into the user friendly file format of PDF (Postscript Document Format) developed by Adobe Software. The PDF file format has many advantages, especially since these files can be viewed and printed through the Adobe Reader software, which is readily available. By this method it is possible to distribute electronic versions of the *Biobibliography* and *History* at a very cheap cost. Paper versions of the files can also be created by those individuals who prefer physical copy in their hands. Several paths are available to accomplish this goal. First download the files to your local computer and use either a home computer with a printer to output the over 2,000 pages or take the files to the local copy bureau and have them print the works double-sided and bound into three volumes.

The text of the *Biobibliography* and *History* are of course subject to change (sometimes radical) in the future. In particular, reference numbers for the individual titles listed in the *Biobibliography* unfortunately change because additions and deletions to entries in the source database cause these numbers to increase or decrease, respectively. The files placed on the internet were created in January 2007 in anticipation of the forthcoming 53st Annual Tucson Gem & Mineral Society Show to be held in Tucson, Arizona on February 8-11, 2007.

Since this is a work in progress, comments and suggestions about the content, format or missing entries are welcome by the compiler. The intention is to bring the work to completion with in the the next few years, so that it can finally be printed as actual physical books. If you wish to contact the compiler, he may be reached through email at the address provided below.

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# Mineralogy & Crystallography: On Their History

## 1.0 Introduction

The purpose of the present text is to provide a concise survey of the history of mineralogy and crystallography through the year 1919. Hopefully, it reflects this rich area of study showing the development of these important scientific endeavors from simple origins through a maturity, which today some might regard as no more than technical art. This is mirrored in the fact that few people now would claim mineralogy as a science balanced on the edge of significant discovery, but that was not the case in the past. Then, mineralogy and its companion study crystallography, were important investigations with each new discovery being widely publicized and debated. Many researchers, some of whom may be counted among the greatest geniuses of the human race, explored, contemplated, and wrote about minerals and crystals. This history tries in some measure to spotlight these people and their discoveries. It is also written as a companion work to *Mineralogy and Crystallography: A Biobibliography*, which fully describes many of the books relevant to these studies across the same time period.

This is a derivative study with little or no attempt to synthesis the motivations and discoveries it presents into a picture that a true historian would write. The intent instead is to provide a general overall view showing how the research and discoveries interlocked to create these important sciences from the simplest of beginnings. Since very broad topics are described, this text necessarily and heavily relies on the many articles and books previously published in the history of these sciences to give its account. To some degree this has caused in several sections a disjointed story to emerge. Hopefully, in the future, further research will allow a rewriting of these sections and thereby smooth out the issues. Sources used in compiling any given section are fully listed in the citations, and the interested reader may consult them for further information.

### Pre-History of Mineralogy

Mineralogy in its most rudimentary form has probably existed since humans developed tools. In the hard, natural life of our ancestors, a case could be argued that it was the junction when man first made flint arrowheads and other stone tools that the first mineralogical studies began. Flint is a rock composed entirely of microscopic quartz crystals, and the ancient tool makers would doubtless had experience in distinguishing hard flint from softer stones. This event may have occurred as long as 25,000 years ago. If it is too much of a stretch to call that moment the beginning of mineralogy, then certainly by the time of the first purposeful recovery of native metals like gold, silver, and copper, man had developed a practical working knowledge of mineral resources. This event probably occurred about 9,000 years ago. Somewhere between those bracketing dates, still well into prehistoric times, must lie the very start of our study.

It is not difficult to imagine the awe that early man would feel in the unexpected discovery of a hard, clear quartz crystal, with its geometric six-sided form clearly displayed. It must have been a remarkable event, and one which early humans would not have been equipped to easily explain. To help, inventions of a divine powers were created to account for the remarkable things of the world. This eventually led man to explain many aspects of the natural world in terms of supernatural powers interacting with the physical world. From this world conception, at an early date, mystical and occult properties were attached to gems, stones, minerals, and metals. Eventually



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this blossomed into a far reaching propaganda that was widely believed.

Later, as civilizations developed, and distinct economic classes separated, those in the upper stratum had time to contemplate the surrounding world. Among the hypothesizes set forth were that minerals and gems contained curative/preventive medical powers. For example, diamond the hardest of all substances, was early on believed to increase strength (in later millennia, the Romans would give diamond other powers). A key link in developing the science was started. Man began to hypothesis about the character of minerals. Of course, true scientific mineralogy requires the unbiased testing of hypothesizes rather than assumed correctness, but the first step, the philosophy had started.

Undoubtedly, mineralogical knowledge must have become reasonably sophisticated, but as the early civilizations were devoured by invading armies or suffered in the environment, and those individuals possessing the necessary knowledge met premature ends, the possibility of significant increases in knowledge approached impossibility. It requires not only a theoretical philosophy but also a means of preserving knowledge for the future to insure a working science. This happened about 1250 B.C.E. somewhere in the Near East (probably Babylon) with the invention of writing. From that time on, the ideas and discoveries of the current generation would be passed to the future, where they could be reviewed, tested and modified, and as necessary ultimately be accepted or denied.

## 2.0 Ancient Studies

Like all science, the study of minerals grew out of practical experience encountered during daily life. Determining which stone could best be broken to a hard, sharp edge for use as a weapon or tool, for example. Grouped together these experiences accumulated into the first tangible beginnings of what today would be called mineralogy. Thus, the study of minerals certainly must rank as one of the oldest studies of humankind. Daily living would have brought early humans throughout their lives into contact with stones, and more rarely natural crystals and native metals. Consequently, a large body of practical knowledge about the mineral world developed in the prehistoric cultures of antiquity, and well before the first records were written. Then when the great civilizations of Egypt, India, and China began to flourish, evidence of widespread mineral knowledge became apparent. In particular, a variety of minerals were thought to have magical or curative properties, that would be bestowed to the human subject if it were worn or ingested. Due to the rarity of some varieties of metals and stones they were further described as "precious" and command expensive prices. Finally during this time, serious attempts were made to copy or produce good fakes of these precious substances, and as a consequence, much was learned about the physical properties and the chemical composition of these materials by the alchemists.

### 2.1 Egypt[1]

The dynastic period of old Egypt can generally be divided into the Old Kingdom, the Middle Kingdom, and the New Kingdom. At the beginning of the Old Kindgom cooper, gold, electrum (a natural alloy of gold and silver) were relatively scarce items, used mostly for ornaments. Vases of rock crystal and colored stone with wrappings of gold leaf tied with string are known. In addition, jewellery of gold, lapis lazuli, carnelian, amethyst, and turquoise have also been recovered from archaelogical sites. The Old Kingdom was largely agricultural in structure, but granite quarries at the First Cataract of the Nile

[1] For further reading see: S. Aufrère., *L'univers minéral dans la pensée Égyptienne*. Cairo, Institut Français d'Archéologie Orientale, 1991. 2 vols. li, 835 p., notes. [Published as: Bibliothèque d'Étude, no. 105]. • M. Clagett., *Ancient Egyptian science: A source book*. Philadelphia, American Philosophical Society, 1989. 2 vols. xv, 863 p., illus, biblio., index. [Published as: *Memoirs of the American Philosophical Society*, no. 184]. • J.R. Partington., Origins And Development Of Applied Chemistry. London, Longmans, Green and Co., 1935. 597 p. [Provides a concise, well referenced account of the sources, production and uses of materials in Egypt, Babylonia and Assyria, Asia Minor, Persia, Syria and Palestine from the earliest times to the end of the Bronze Age].

were begun, followed by the extraction of huge blocks of sandstone at Silsileh. Harder and finer stones were obtained from the areas between Coptos and the Red Sea. By the end of the Old Kingdom, limestone was recovered from many areas, with the blocks being cut with tubular copper drills and notched copper saws with sand used as an abrasive. Mouth blowpipes were probably a hollow reed tipped in clay as shown in the tomb of Beni Hasan and for a long time mistaken to be for glass blowing. Bronze was at the time unknown, and iron was not yet used for cutting stone, although perhaps used in a small extent for other tools. It is clear, however, that from the earliest times, the Egyptians possessed considerable knowledge of the technical arts and of minerals.

The Middle Kingdom is associated with the rise to prominence of the city of Thebes. During this period, mines of gold, silver, electrum, copper were activily prospected and worked with slave labor. For example, the output of the Nubian gold mines was improved and the working of the copper mines in Sinai were reorganized to be worked throughout the year, where previously they had only been worked in the cool months. Each mine had a foreman, and there were periodic visits by officials from the treasury. Bronze, an alloy of copper and tin, came into common use, and there was extensive commerce with Egypts neighboring civilizations. This activity built up considerable wealth within Egypt.

The New Kingdom brought the widespread acceptance of gold and silver as items of value used in commerce. Conqured nations such as the Syrians paid tribute to Egypt in silver, lapis lazuli, malachite, turquoise, precious stones, bars of lead, copper, tin and bronze. Fine gold, ivory, ebony, precious red stone and precious yellow stone were obtained from the Nubians. Metal work and jewellry creation during this period shows a high quality. Precious stones were shaped and polished, and high temperature annealing and soldering is seen in the goldwork of the time, and may have been influenced by Minoan originals. Some tomb paintings show the weighing of precious materials, bars of metals, bronze, lapis, malachite, etc. indicating an extensive trade in minerals between Egypt and the outlying countires perhaps as far east as India. The fabulous objects found in the tomb of Tutankhamen who ruled towards the end of this period, contain finely worked gold items inlaid with glass and stone, as well as statues made from copper, bronze, alabaster, turquoise, malachite, etc.

### 2.1.1 Ebers Papyrus[2]

The Ebers Papyrus, said to have been discovered in a terra-cotta jar between the legs of a mummy buried 10 feet deep at Thebes about 1900 B.C., is 20 meters long and 30 cm wide. The content of its 39 small treatises provide some of the earliest accounts of medical and chemical preparations that have been preserved from antiquity, and many of these have probably been compiled from still earlier sources (perhaps centuries older). Its subject matter would indicate that it is a collection of prescriptions and reciepes used by physcians, cosmetitians, hair-dyes, hair restorers, pest exterminators, etc. Most of the concoctions described are of organic, especially vegetable, origin, showing that the Egyptians were familiar with a large number of plants, but some are mineral in nature, such as copper sulfate, salt, natron and aner sopdu (Memphite stone).[3] The prescriptions described in the papyrus closely resemble the structure of those found in the medical and receipe books published in Europe in the seventeenth and eighteenth century.

### 2.1.2 Leyden & Stockholm Papyrus[4]

[2] Other studies include: C.P. Bryan., *Ancient Egyptian medicine: the Papyrus Ebers.* Translated from the German version by C.P. Bryan, with an introduction by G.E. Smith. Chicago, Ares Publishers, 1932 [Reprinted, 1974]. xl, 167 p., plates, illus. • H.L.E. Lüring., *Die uber die medicinischen Kenntnisse der alten Agypter berichtenden Papyri: verglichen mit den medicinischen Schriften griechischer und romischer Autoren.* Leipzig, 1888. 170 p. • J.F. Nunn., *Ancient Egyptian medicine.* Norman, University of Oklahoma Press, 1996. 240 p., illus., map.

[3] Berthelot [p. 185]

[4] Other information may be found in: R. Halleux., *Les alchimistes grecs. 1: Papyrus de Leyde, papyrus de Stockholm, fragments et recettes.* Texte établi et traduit par Robert Halleux. Paris, Les Belles Lettres, 1981. 235 p. (84-151 double), biblio., index. • *ibid.*, *Indices chemicorum graecorum. I: Papyrus Leidensis, Papyrus Holmiensis.* Roma, Ateneo, 1983. xxv, 135 p. [Published as: Lessico Intellettuale Europeo, no. 31]

It is recorded that around 290 c.e. the Egyptian emporer Diocletian fearing the art of alchemy decreed that all works and ancient books describing the alchemical arts or gold and silver be destroyed. This caused the disappearance of a mass body of literature that doubtless would have provided a great insight into the ancient ideas about the history of chemistry and the knowledge of minerals. The previously mentioned Ebers papyrus escaped destruction as did two other early Egyptian Papyrus that deal with chemical and mineralogical matters. These were most probably recorvered from the tomb of a high ranking apothecary who died in Thebes before 290 c.e. and are known today as the Papyrus X of Leyden and the Stockholm Papyrus. They are important for shouwing numerous chemical processes and recipes for alloys, metal working, dyeing, making imitation precious stones and similar arts. Based on their content they are thought to be mid-Third Century copies of a work first writtin in the First Century b.c.e. In addition, both the Leyden and Stockholm papyrus are apparently derived from the same, now lost, work.

The Leyden papyrus comprises about seventy-five reciepes several of which have been extracted from the Materia Medica of Dioscorides. Methods for writing in gold or silver are given as are descriptions of how to dye the surface of metals. Lists of materials required are presented. The Stockholm papyrus contains about 150 reciepes. The two manuscripts practically duplicate each other with some rearrangement and reworking of the same reciepes. The parts describing metals are largely concerned with the trasmution of gold, silver or electrum from cheaper materials, or giving an artificial color to the cheaper material to convey a preciousness. The nomenclature of the materials is essentially that of Dioscorides with few changes in the meaning of his terms, although in some cases the Latin equivalents of Vitriuvius and Pliny are used.

## 2.2 Babylonia & Assyria

Mesopotamia located between the Tigris and Euphrates rivers and rising in the mountains of Asia Minor and extending to the Persian Gulf was the site of an ancient civilization that riveled in many ways Egypt. While the earliest remains probably go back to 4000-3500 b.c.e., the earliest dated sites are from 3100-3000 b.c.e. The earliest civilization in the area was agricultural, however, as villages became towns, craftsmanship and knowledge of the mineral world expanded. Graves from this early period contain stone bowls, gold, silver, copper pots, as well as jewellry inlaid with lapis lazuli, mother-of-pearl and other stones. From the earliest period, the Sumerians one group who occupied the land were familiar with the use and sale of gold, silver, copper and certain precious stones. They also worshipped gods related to metallurgy, and like the Egyptians they regarded the setting sun as passing through the lower hemisphere as the god of the treasurers of the underworld.[5]

Metal working and related crafts were apparently known from the earliest times in Babylonia and Assyria; however, there appears to have been no local source material in Babylonia and the deposits of copper, lead, silver, antimony and salt were probably not worked by the Assyrians. Instead, the merchants of these regions bartered with other countries, most probably Egypt for raw material that could be worked by local craftsmen. The bellows was employed to generate high temperatures in the furnace and on the anvil. There was none the less a large knowledge of metals, minerals and precious stones, so much so that a modern dictionary of terms was compiled for this ancient civilization.[6] Thus gold was known and used for jewellerry of rings, neckleaces, buttons, studs, bracelets and earings, usually inlaid with other materials like glass or precious stones. Electrum (gold alloyed with silver), silver, copper, tin, lead, iron and antimony were all known. In addition, the first Bronze

[5] M. Levey., *Chemistry and chemical technology in ancient Mesopotamia*. Amsterdam, New York, Elsevier Pub. Co., 1959. xi, 242 p., illus., map (on lining papers). • A. Leo Oppenheim., "Man and nature in Mesopotamian civilization" (**15**, pp. 634-666) in: C.C. Gillispie, ed., *Dictionary of Scientific Biography*. • Partington, *Origins*, 1936, , p. 216.

[6] Thomson, R.C., Dictionary of Assyrian chemistry and geology. Oxford, 1936.

Age objects dating to about 3500-3000 B.C.E. were found in this region, with occurances throughout the history of the civilizations, indicating a sophisticated knowledge of copper and tin alloying. Polished hæmatite was used for making small objects such as weights, cylinder seals, rings, bracelets, bangles, studs and personal ornaments. But iron in this state was costly and rare. Iron of meteoric origin also seems to have been available in small quantities to the Babylonians. Interestingly, the long held association of certain planet gods with specific metals seems to have originated with the Sumerians. For example, silver is related to the moon, gold to the sun, lead to Saturn, etc.

Stone for building purposes was quarried and consisted of diorite, alabaster, dolomite, limestone, breccia and basalt. It was used to erect temples, palaces and more permanent structures. In addition, stones used for utilitarian purposes such as mill stones were quarried within the region. Bitumen or asphalt is known in several locations in Mesopotamia. It was used in creating mortar for cementing limestone blocks or bricks together, as well as water proofing reed baskets and the hulls of boats, medicinal salves, and incendiary bombs during periods of war. Naptha or petroleum could usually be found at the bitumen deposits and this was used for lamps in the homes and temples. It may have also been poured on the heads of attackers of the cities and set alight.

Gemstones were known and appreciated from the earliest period by the Sumerians, who had access through trade to many types and varieties. Cutting of the gems and jewellry creation was an early industry, and through trade stones from Susiana, Arabia, the Pamiers, Eastern Asia, Egypt, Nubia and India were known. Agates, beryls and sardonyx from Choaspes, amethysts from near Petra, and alabaster from Damascus, jasper from near Zenovia on the Euphrates have been identified from archaeological sites. Bead necklaces of roughly chipped rock-crystal, carnelian, lapis lazuli, jasper, garnet, chalcedony, obsidian and shell are also known. Colored glass, perhaps used to imitate natural stones, has also been found in the region.

There was a strong belief in the curative and magical powers of metals and certain stones. Together with herbs, seeds, woods, milk, cream, butter, copper, silver, gold, stones and gems could be added to water and prescribed by the medical professionals as a curative for many ills. Pure things such as copper, gold and silver were thought to benefitial when handled or touched. Hundreds of tablets describing medical treatments and prescriptions are preserved in the British Museum.[7] Methods of perparing various cures is preserved. Included is the notion that the smell of copper dust is enough to cure some diseases. Plants and minerals are thought of in terms of female and male. The male gender is often stronger and darker that the female type. Partington (1936) provides a useful list of mineral drugs listed in Assyrian texts.[8]

## 2.3 The Ægean (Crete)

After the Egyptians, a choice of material is available for further consideration. The regions of present day Greece, and the lands of Asia Minor and the Middle East all developed considerable civilizations. Following their developmental sequence in time, the next early people to appear were on Crete at Knossos, which would be the center of the whole Ægean culture. The first settlement of man in the Ægean region was probably at Knossos in the later (Neolithic) Stone Age. Other ancient sites exist in Crete and the Phylakopi in Melos is also an old site, but not as old as Knossos. Few remnants of the Stone Age society exist. Their Bronze Age, was characterized by advanced metal work and pottery glazed with different colors. Although attempts were sometimes made to regarded it as a prehistoric Greek civilization, the Ægean culture is more related to Egypt than to the European Greeks, who were of a different race.

Relations between early, perhaps Predynastic, Egypt and the Ægean were intimate. Like that well-known society, builders and artisans in the Ægean developed a well crafted

[7] A useful account has been compiled by: Küchler, Beiträge zur Kenntniss der assyrisch-babylonischen Medizin. Leipzig, 1904.

[8] Partington, *Origins*, 1936, , p. 316-317.

technology that included stone axes, serpentine maces, obsidian knives, and stone and clay spindle whorls, but the only trace of metal was one copper axe, perhaps imported from Egypt. Ceramics were decorated from a very early period with no break indicated between the Stone and Bronze Ages.

Although there is little or no indication that metals were mined in Crete in ancient times, the island had the reputation of being peopled by skilled metallurgists. Gold, silver and copper objects, both utilitarian and ceremonially, have been found at all of the Ægean sites. The goldsmith's work was very similar to the very fine silver work recovered at Troy in Asia Minor. Based on analysis most of this metal came mostly from Nubia by way of Egypt, perhaps through Libya, where there were one or two Minoan settlements and an established intercommunication. Silver was also used in large quantities, and is found in pottery, jewelry, and coins of the society. Weapons of copper including daggers, spearheads and axes, have been recovered, with the metal having been imported, probably from Africa.

Seal cylinders of agate, steatite, jasper, magnetite, and hematite dated from about c2000 B.C.E. have been found, showing that the lapidaries of Crete were highly skilled in their craft. Other engraved gems and stones of various dates include deep purple amethyst, transparent paste onyx, carnelian, bloodstone, iridescent glass, hyacinth, sard, yellow and red jasper, sardonyx, agate, garnet, spinel, greenstone, basalt, and colored glass. Some ornamental objects as well as beads made from lapis lazuli are also known. Pliny said that diamonds could be found in Crete but these are not true diamonds, but probably sapphires or rock crystal. Other gemstones mentioned as originating from Crete include amethyst, emerald (probably chrysoprase?), aquamarine, opal, agate, jasper, and coral. Dioscurides mentions asbestos, which has been mined in Cyprus in modern times.

The Bronze Age also came to Knossos and Crete with vases and basins, with the necks or rims soldered on, have been found at Knossos. Other bronze objects including vases, cups and utensils became common and with weapons finally appearing in great numbers.

Legends preserved by Hellenistic authors also say Crete was the supposed home of mythological beings. At the root of these fables are perhaps the many and varied fossil bones that are found in the Jurassic stratum of the land. Another ancient legend may have at its roots the events that occurred on one island of the Ægean civilization, Santarini. It has been shown that this island was once home to an advanced, ancient civilization, that was destroyed when the island's volcano erupted in prehistoric times. This extinction may be at the root of the fabled legend of Atlantis. In any event after the catastrophic tsunamis that followed the eruption spread throughout the Mediterranean, this ancient society noticeably declined.

## 2.4 Troy (Hissarlik)

Troy and the Trojan Wars are given full colorful decriptions in Homer's masterful works, the *Illiad* and the *Odessy*. These tales, thought for milennia to be a work of imagination, were shown through the excavations by Schliemann in 1870-1890 to have decribed an actual prehistoric city. This is Hissarlik, the ancient citadel of Troy. It is located on a what is now a large plain, but in its time was a broad shaped peninsula, near the the mouth of the Dardanelles. Its location rises from the level of the plain to a low spur, 50 feet in height, which is covered with layers of ruins dating back to probably c2000 B.C.E..

The walls of the city are made from a porous limestone, while other building of various times are made from sun dried bricks. In several instances marble and other stone was used. Also clay earth and chalk, perhaps imported from other lands, were used. Many objects of metal, stone, and gems have been recovered from the locality. Gold, silver, copper, bronze, and lead, were worked with great skill. Ivory and jade, imported from Africa and perhaps as far away as India have been found. Mica-schist and granite moulds used in the casting of metals using an oper hearth have been recovered. Other crucibles and funnels of clay used in metal work are also

known. Ornamental jewelry fashioned from gold, silver, and copper that contains rock crystal, amethyst, jasper, coral, and similar material has been found in the burial tombs of the ancient citizens.

### 2.5 Asia Minor[9]

One of the great crossroads of ancient civilizations is a broad peninsula that lies between the Black and Mediterranean seas. Called "Asia Minor" (Lesser Asia) by the Romans, the land today forms the greater part of modern Turkey. It lies across the Aegean Sea to the east of Greece and is usually known by its Greek name Anatolia. The land of Asia Minor is among the first cradles of human civilization. Some of the earliest Neolithic settlements discovered in the Middle East have been found in Asia Minor. It was the original location of the kingdom of the Hittites (c1900-1200 B.C.E.), with the west coast being settled by the Greeks (1000-750 B.C.E.). It was conquered by the Persians in 546 B.C.E., and remained under Persian rule until the 4th century B.C.E., when it became a Macedonian territory ruled by Alexander the Great. Under Alexander's successors, the land was divided and redivided many times by many rulers. It was slowly taken over by the Romans. In 395, after the division of the Roman Empire the land became a center piece of the Byzantine Empire. It was overrun in the 7th century by the Arabs, and in the 11th century the Turks set up a sultanate.

#### 2.5.1 The Hittites[10]

Records of the Egyptians and Mesopotamians cite the Hittites as one of the peoples inhabiting Asia Minor. They probably migrated to the region by way of the Caucasus around 2000 B.C.E.. Archae logical evidence supports the fact that like the Egyptians, they early on developed a written language, and based on these records and those of other surrounding civilizations they expanded their territory through many wars.

The Hittites and related tribes of Asia Minor worked their land for minerals from an early period. They operated mines in the area providing nearly every kind of mineral and exporting metals to the ancient world. Even during the Roman period, even though some deposits had been worked out, others were still profitably exploited.

The Hittites mined vast quantities of silver and developed metallurgical techniques to refine and alloy it. In their language silver was called "khattus". Several locations were important including one town called 'Boghazköi' that means "town of silver". Artifacts of pure silver have been recovered. These are objects of ceremonial and decorative purposes.

Copper and bronze were also developed in Asia Minor. Swords, spears, and other weapons, house hold items, and decorative objects with inlaid rock crystal, jasper, carnelian, lapis lazuli, and shell have been recovered. Lead in the form of galena was mined, smelted, and exported to other lands. Mercury in the form of cinnabar was also recovered at some of the richest mines of the ancient world. Sulfides of arsenic in the form of orpiment and realgar were like wise mined.

### 2.6 Persian Empire

The Persian Empire was a series of historical empires that ruled over the Iranian plateau and the adjacent lands. The political entity which was ruled by these kingdoms is the country of Iran (literally "Land of Aryans"). Generally, the earliest entity considered a part of the Persian Empire is Persia's Achaemenid dynasty (648-330 B.C.E.), a united Aryan-indigenous kingdom that originated in the region now known as Fars and was formed under Cyrus the Great. Successive states in the region of Iran prior to 1935 are collectively called the Persian Empire by Western historians.

The Iranian plateau has given up very old remains of civilizations dating to about 3000 B.C.E.. The earliest of these settlements show no metal but contain crudely formed pottery. Later remains include objects of

[9] Heleen Sancisi-Weerdenburg and Amelie Kuhrt, eds., *Asia Minor & Egypt: Old Cultures in a New Empire*. Leiden, Eisenbrauns, 1991. xviii, 367 p.

[10] J.G. MacQueen., *The Hittites: And Their Contemporaries in Asia Minor*. Revised edition. London, Thames & Hudson, 1996. 176 p.

bronze, copper, gold, and silver. Copper implements include narrow chisels, needles and mirrors. Because the copper contains trace quantities of antimony, arsenic and lead, it is suspected that the copper originally came from central Asia. Ornamental objects including beads made from carnelian, lapis, shell, jasper, and finger rings have also been recovered.

An Iranian civilization probably existed from a very early period, but little is known of it before about 550 B.C.E.. They were influenced heavily by the Assyrians, particularly in their language, but they developed their own unique civilization. Early Persian authors say much about the early battles between the Iranian people and surrounding tribes, but much else about their early history is shrouded in mystery. Their country formed a bridge between the civilizations of Asia and the Mediterranean, and consequently, it reflects the influences of both the east and west.

At its height the Persian Empire was a territory of enormous extent embracing the whole of today's Middle East and parts of western Asia. IT was also a very wealthy civilization. Many objects including statues and household items made of bronze, copper, silver, and gold have been recovered. The Persians made much use of pearls, emeralds, rubies, sapphires, diamonds, laps, agates, amethyst, hematite, quartz and other stones in many objects including jewelry. They recovered minerals from many mines scattered through out their territory, and produced most of the metals used by the ancient civilizations.

## 2.9 Palastine[11]

An ancient country, called the Pelesheth in the Bible, and popularly known by it Greek name Palestine is a long broad strip of land located at the eastern end of the Mediterranean. Roman and Greek authors meant the whole region of the Jews, east and west of the River Jordan, and what is known to Christians as the Holy Land. However, in prehistoric times, it was occuppied by the Semites, the oldest branch known as the Canaanites, which first appear about 2500 B.C.E..

The early peoples of Palestine were influenced by Egypt, Babylonia, and the Aegean cultures. Early trade with Egypt shows that gold, silver, copper, lead, and ivory were sent from Palestine abouth 1500 B.C.E., but the region at the time also incorporated the whole of Syria and a large portion of Asia Minor. Amulets that had inlaid precious stones worked as magical talismans were imported from Egypt.

The old Hebrew tribes known collectively as the Israelites first appear about 1250 B.C.E. and settled the region by the 14th century. They orignally spoke Aramaic and probably adopted the Hebrew language from the Canaaites. The famous Exodus is an obscure event with the best known refrence in the Old Testement.

Paleolitic cultures are associated in Palestine with crudely chipped flints found throughout the region. Rudimentary pottery developed into sophisticated clay ware that were highly decorated objects, with designs made with glazes derived from copper, lead, and other minerals. Glasses, tinted with mineral salts are known from 2500 B.C.E., and show Babylonian, Egyptian, Cyprian, and Creatian influences.

Metals used in Palestine were gold, copper, silver, bronze, brass, lead, and iron. Gold was however, rare, and was not much used. Bronze was probably imported as ingots and worked by the local craftsmen. Objects of silver including jewelry and household objects date from 1100 B.C.E.. Copper, bronze, brass was also used from the same time and made into knives, chisels, daggers, axes, saws, spoons, statues, etc.

### The Bible

The old testement of the Bible as an historical document provides information on ancient Palestine. The precious stone (yëqârâh) was early in use and several kinds are frequently named in the Old Testament, although their identification is very uncertain. It mentions

[11] Other historical information may be found in: Immanuel Löw., *Fauna und Mineralien der Juden*. Herausgegeben und mit einem Vorwort und Anmerkung versehen von Alexander Scheiber. Hildesheim, G. Olms, 1969. xiii, 282, [11] p., portrait. [Describes the animals and minerals in rabbinical literature and the Old Testement.]

an astonishing totat of 1,704 references to gemstones and minerals under 124 Greek and Hebrew names. These contain descriptions probably based on information based on Greek knowledge. Their identification is, however, like those of other classical authors and very conjectual. For example, the twelve stones of Aaron's Breast Plate has been variously described.[12] The usual identification of the stones is given as:

| | | |
|---|---|---|
| Jasper (Sardius) | Citrine (Topaz) | Emerald |
| Carbuncle | Lapis Lazuli | Rock Crystal |
| Golden Sapphire (Ligure) | Blue Sapphire | Amethyst |
| Yellow Jasper | Onyx | Chrysoprase (Jasper) |

Stones of the High Priest's Breastplate

## 2.10 Ancient China[13]

That huge region today called China and occupying a prominent place from central Asia to the Pacific coast was the home of an early civilization. Early on the Chinese possessed a high degree of artistic quality in their decorative arts. This included creating fabulous carvings in jade and other stones[14] that date from the — — — period (— — — B.C.E.). Gemstones such as diamond imported from India were also very important.[15] In early Chinese writings on mineralogy, stones and rocks were differentiated from metals and alloys, and further characterized by color and other physical properties.

The most remarkable of these writings were a series of pharmacopoeias that included descriptions of plants, animals, and minerals, together with commentary on their therapeutic values. Like the herbals of western tradition, these Chinese counterparts were highly popular, and many variations appeared. The *Chi Ni Tzu* that may date from the fourth century B.C.E. includes a list of twenty-four inorganic substances. The first century *Shen Nung Pên Tshao Ching* (Pharmacopoeia of the Heavenly Husbandman) that once was a separate work, became incorporated with the commentaries of the later *Pên Tshao* books (1596). It describes forty-six mineral substances, arranging them into three categories based on their value as therapeutics.

All subsequent appearances of the *Pên Tshao* began with sections describing minerals substances, though some treat them more fully than others. Thus, 215 minerals are treated in the *Chêng Lei Pên Tshao* (Recognized Pharmacopoeia) edited by Thang Shen-Wei around 1115 C.E., but only two or three appear in the 670 C.E. *Shih Liao Pên Tshao* (Nutritional Medicine Pharmacopoeia) of Mêng Shen. An elaborate treatment of 217 minerals occurs in the culmination of the series, *Pên Tshao Kang Mu* (The Great Pharmacopoeia) of Li Shih-Chen written about 1596. These minerals are well described because a collection labeled specimens to those described corresponding to those mentioned by Li Shih-Chen were transported from China to Europe in the eighteenth century. There they were analyzed in the following century and fully

[12] ?????

[13] For further historical information, see: William Frederick Collins., *Mineral enterprise in China*. London, W. Heinemann, [1918]. xi, [1], 308 p., maps (partly folding). [Mines and mineral resources of China.] • Ch'iao-p'ing Li., *The chemical arts of old China*. Foreword by Tenney L. Davis. Easton, Pennsylvania, Journal of Chemical Education, 1948. viii, 215 p., 83 b/w illustrations, pictorial endpapers, appendices. • J. Needham., *Science and civilization in China*. Cambridge [England], University Press, 1954. [See volume 3, sections 23 (geology) and 25 (mineralogy)].

[14] S.C. Nott, *Chinese jade throughout the ages*. Second edition. • Berthold Laufer., *Jade*. A Study in Chinese Archaeology and Religion. Chicago, Field Museum of Natural History, Publication 154, Anthropological Series Vol. X, Chicago, 1912 (reprinted in China, 1941). xiv, 370 p., 68 plates, text illus. [In the history of Chinese mineralogy the work of Keng Hsin Yü Tshe of the Ming Dynasty on jade is important.]

[15] Berthold Laufer., *The Diamond: a Study in Chinese and Hellenistic Folk-Lore*. Chicago, Chicago Field Museum of Natural History, 1915. 75 p. [Published as: *Field Museum of Natural History Publication 184*, Anthropological Series, **15**, no. 1.] • T. Wada., "Schmuck und Edelsteine bei den Chinesen," *Mitteilungen der Deutschen Gesellschaft für Natur- und Völkerkunde Ostasiens*, Tokyo, **10** (1904), p. 1-16.

described by Biot[16] and Mély.[17] In 1878, Geerts using a Japanese commentary of the *Pên Tshao Kang Mu* also made a study of its section on minerals,[18] and it was the source for another valuable descriptive catalog.[19]

Outside of pharmacy, Chinese literature contains other mineralogical works. In the Thang dynasty about 818 C.E. the important treatise *Shih Yao Erh Ya* (Synoptic Dictionary of Minerals and Drugs) was prepared by Mei Piao. This is a remarkable glossary of terms used by Thang dynasty alchemists, listing 335 synonyms for sixty-two chemical and mineral substances. Scientific writings came to the fore during the Sung dynasty and several books devoted to minerals appeared. One of the earliest was the *Yüyang Kung Shih Phu* (Treatise on Stones by the Venerable Mr Yüyang) written in the eleventh century, but little remains of the work. About 1120 the Szechuanese monk Tsu-Khao prepared the *Hsüan-Ho Shih Phu* (Hsüan-Ho Reign Period Treatise on Stones), which described sixty-three different stones, but only the table of contents is extant. Perhaps the most important work of the era is the *Yün Lin Shih Phu* (Cloud Forest Lapidary) authored by Tu Wan that dates to about 1133.[20] It describes 110 stones and minerals.

During the Ming and Chhing periods scientific writings tapered off considerably. The handful of mineralogical works that appeared include the 1617 *Shih Phin* (Hierarchy of Stones) that was written by Yu Chün, the smaller 1665 *Kuai Shih Tsan* (Strange Rocks) by Sung Lo, and the 1668 *Kuan Shih Lu* (On Looking at Stones) by Kao Chao.

[16] ????

[17] Mély, *Les Lapidaires Grecs*, 1898-1902, **1**, p. ??-??

[18] A.J.C. Geerts, *Les Produits de la Nature Japonaise et Chinoise*. Yokohama, 1878-83. 2 parts. [8], xi, [1], 294, [2] p., 15 plates.; [4], [295]-662 p., 8 plates

[19] Bernard E. Read and Phu Chu-Ping Pak. "A compendium of minerals and stones used in Chinese medicine, from Pên Tshao Kang Mu, Li-Shih-Chen, 1597 A.D.," *Peking, Society of Natural History Bulletin*, **3** (1928, no. 2, [i]-vii, [1]-120 p. [Revised and reissued separately, French Bookstore, Peiping, 1936, 2nd edition.]

[20] English transl., Wan Tu., *Stone catalogue of Cloudy Forest*. A commentary and synopsis by Edward H. Schafer. Berkeley, University of California Press, 1961. 116 p., illus.

## 2.11 Ancient India[21]

The Indian subcontinent including the present days countries of Pakistan and Bangladesh was the incubator of ancient civilizations. Evidence suggests that parts of the region were settled as early as 8000 B.C.E. Remains of the Paleolithic and Neolithic age contain stone tools made of flint. There is also evidence at prehistoric sites that minerals were used as coloring agents in potteries.[22] Although rare, ornamental beads of agate and other stones, as well as implements and jewelry made from copper have been dated to the earliest period. India is rich in metals, minerals, and especially gemstones that were easily recovered from alluvial deposits along the rivers, so it is not suprising that early on a good practical knowledge of metals and minerals developed.

In the Indus valley the Harappan civilization developed in prehistoric times and flourished to about 1500 B.C.E. when earthquakes caused some channels of the river to dry up and large populations to relocate. The archaeology sites show evidence of a wide use of minerals. Highly decorated clay pottery and glass colored by mineral pigments are known. Metallic objects made of gold, silver, lead, and copper have been recovered. Beads and other ornamental

[21] Other information may be found in: A.K. Biswas., *Minerals and metals in ancient India*. Report on sponsored work (1987-91) submitted to Indian National Science Academy, New Delhi. New Delhi, D.K. Printword Pvt. Ltd, 1996. 2 vols. (I: 524 p.; II: 259 p., plates, biblio., index). [Volume I 'Travellers' accounts and archaeological evidences'; volume II 'Literary Evidences.'] • *ibid.*, "Gems and minerals in ancient India," (**1**, 401-467) in: A.K. Bag, ed., *History of Technology in India*. New Delhi, Indian National Science Academy, 1997. 2 vols. (I: From Antiquity to c1200 A.D., xl, 717p.; II: From 1801 to 1947, A.D., xix, 1036 p.) • R. Krishnamurthy., "Gemmology in ancient India," *Indian Journal of History of Science*, **27** (1992), p. 251-60. • K. Muthulekshmi., *The history of Indian chemistry*. Paper presented at the National Seminar on Scientific Heritage of India at the University of Calicut, Kerala from July 1-4, 2000. [internet citation]. • M. Ray., "Minerals and gems in Indian alchemy," *Indian Journal for the History of Science*, **26** (1991), p. 133-54. • Moriz Winternitz., *A history of Indian literature*. Translated from the original German by S. Ketkar, and revised by the author. New York, Russell & Russell, 1927-31. 2 vols. [History and criticism of Sanskrit literature indigenous to India.; Reprinted, 1971.]

[22] Prafulla Ray., *History of chemistry in ancient and medieval India incorporating the history of Hindu chemistry*. Calcutta, Indian Chemical Society, 1956. 494 p., illus.

objects made of local stones and imported lapis lazuli and turquoise have been discovered. The remnants of high temperature furnaces and firing pots are also known.

Probably during the Vedic period (3000 - 600 B.C.E.) precious stones were identified as jewels (maṇi) and separated from more common materials. The fine polish given to rocks, minerals, and gems of the period show that the technical art of polishing had reached a high level. The process involved garnet and corundum grit of decreasing size used to flatten, smooth, and finally polish the stones surface. Iron and a bronze like alloy of copper and tin were discovered late in the period.

The Harappans developed extensive trade within and outside of India. Like the ancient cultures of the Middle East they made many articles out of metals, semiprecious stones and other minerals. India was linked by land and sea routes to central Asia, Afghanistan, and Iran and is evidenced by the discovery of tin, lapis lazuli, turquoise and other minerals not native to the Harappan culture at various archaelogical sites.

Indian medicine consisted mainly of drugs made from native plants. However, other medications employed minerals. Sanskrit texts mention the use of bitumen, rock salt, yellow orpiment, chalk, alum, bismuth, calamine, realgar, stibnite, saltpeter, cinnabar, arsenic, sulfur, yellow and red ochre, black sand, and red clay in prescriptions. Among the metals used were gold, silver, copper, mercury, iron, iron ores, pyrite, tin, and brass. Mercury appeared to have been the most frequently used, and it is called by several names in the texts.

During the Buddhist period (600 B.C.E.-1200 C.E.) the trade routes were extended to far away cultures. The Sumerians and Egyptians were trading for Indian products. Precious stones imported from India were used as decorations in the breast plates of their high priests. The Minoan, Phoenicians and Cretan traders appear to have also had an active commercial trade with India. The subcontinent was linked by land and sea routes to central Asia, Afghanistan, China, and Iran. That trading occurred with these regions is shown by the discovery of lapis lazuli, turquoise, and other minerals not native to Indian territory. Around 25 B.C.E. the Romans began commercial commerce with India that would last for centuries. Pliny mentions frequently that India is the source of many minerals and gems. Various goods desired by the Romans and in very great demand included agates, onyx, rock crystal chalcedony, bloodstone, red jasper, opal, sapphire, ruby, jadeite, moonstone, aquamarine, emerald, garnet, zircon, pearls, ivory, and diamond. India in exchange brought in from the Roman Empire copper, lead, arsenic (realgar, orpiment), antimony (stibnite), mercury (cinnabar), and tin.

### Gemology (Ratnaparikṣâ)

India and old Ceylon, an island located off its southeast coast, remained throughout ancient times and until the eighteenth century the single known source for diamonds, emeralds, sapphires, and other precious gems. The ceaseless commerce that built up around the gemstone trade little by little brought about a series of rules that guided the Indian merchants in estimating the values of gems that evolved into a common law of transactions. Stones were cataloged, their density measured, as were other characteristics like color and sparkle. Lists were compiled describing a stones qualities and defects. All localities that were sources for the gems were also recorded, which allowed a detailed comparison to distinguish specimens form different locations.

Later, as skillful forgers made good imitation jewels, and it became necessary to discover means of recognizing authentic gems form other material. The whole of observations formed a body of doctrines called 'ratnaparikṣâ' (appreciation of the gems). The oldest mention of *ratnaparikṣâ* occurs in the ancient *Kàmasàtra*.

In the *ratnaparikṣâ* tradition, colors and the places of origin were fully used to catalog the qualities, defects, and set a price of the stones. It is, however, not clear when this general knowledge was formally compiled and recorded in a formal treatise. But Finot firmly believed that it was well before the Christian

era. [23]

It would be a mistake to consider the *ratnaparikṣâ* as a simple handbook for the use of jewelers. Undoubtedly, it formed a necessary tool to one of the chief branches of commercial instruction. The skill to examine and judge the quality of the gem rough was a valuable talent that was vital to creating the best cut stones. But the *ratnaparikṣâ* also formed an early method to distinguish gem mineral by means of physical properties.

Knowledge of how the early Indian societies viewed precious stones and other minerals is preserved in a few ancient and precious Sanskrit manuscripts. Finot in his indispensable *Lapidaires Indiens* (1896) gives descriptions and French translations of six of these ancient Indian works. Gemology transmitted through the doctrines of *ratnaparikṣâ* was transmitted in a series of more or less complete treatises across several centuries.

1. — *Ratnaparikṣâ* of Buddhabhatta

This work consists of 252 stanzas of a varied meters and is attributed to a Buddhist named Buddhabhatta. Of this author, nothing including the period in which he lived, is known. His work appears also not to be an original work, but a shortened version of an unknown manuscript. The compiler, himself, indicates that he is presenting a simple summary of the *Ratnaparikṣâ* that treats the principle gems.[24]

2. — *Bṛhatsaṃhitâ* of Varâhamihira

This is also a long fragment of the *Ratnaparikṣâ*. It was compiled by Var$^{a}$hmihira [505-587 c.e.]. Finot believes it to have been written using the same source material as the work by Buddhabhaita had accessed, because based on textual content, neither text was the direct source for the other. It enumerates 22 species of stone of which 16 are common to the Buddhabhatta book. Also, the scale of prices used to value diamonds differs somewhat in the two texts, but the method for determining values is identical. This strongly points to another *Ratnaparikṣâ* having once existed that was the source for both of these other books, but which a rather complete summary is given by Buddhabhatta and a long fragment by Varâhamihira.

These works were themselves used as sources, usually with major rewriting and almost always unattributed. The *Garuda-Purāna* of the thirteenth century contains many entries on gemstones without citation. Another compilation entitle, *Gai-nda-Purāna* also was derivative of the earlier work.[25]

3. — *Agastimata*

The *Agastimata* is one of the most important extant early treatises on precious stones. Although generally, it has features common with Buddhabhatta's work, the detail it offers differs so much, they must be regarded as representatives of two states of the tradition that have significantly diverged from one another. The *Agastimata* appears, therefore, to be a more recent transmission of its information, with elaborate descriptions and a precise nomenclature. Unfortunately, the date of composition of this work can not be achieved with any accuracy. Because of its description of pearls, Finot says it was written well with in the Christian era, and was probably composed in southern most India.[26]

4. — *Navaratnaparikṣâ*

The *Navaratnaparikṣâ* is a good summary of knowledge of precious stones, written in a clear and simple style. It was known by Finot in two manuscript recessions, the longest being 183 stanzas.

5. — *Ratnaparikṣâ* of Agastiyâ

The *Ratnaparikṣâ* is known in only a single manuscript. It is a compendium of approximately 100 stanzas that repeats traditional doctrines on the gems. Attributed to Agastiyâ, it is according to Finot original in its detail, but is unfortunately corrupted with serious gaps in the text.[27]

6. — *Laghu-Ratnaparikṣâ*

The *Ratnasangraha* is a short summary in 22 verses, with each stone the subject of two stanzas, the first enumerating the stone's qualities, and the other giving the defects.

[23] Finot, *Lapidaires Indiens*, 1896, p. ??

[24] Finot, *Lapidaires Indiens*, 1896, p. vi.

[25] Finot, *Lapidaires Indiens*, 1896, p. ?? — 1812 edition.

[26] Finot, *Lapidaires Indiens*, 1896, p. ??

[27] Finot, *Lapidaires Indiens*, 1896, p. ??

According to Finot, it is in the form of a dialog between Çiva and P[a]rvat[i] discussing the virtues of stones.

## 2.12 Ancient Greece

Ancient Greece was the cradle of an early and influential civilization. About the sixth century B.C.E. the change from a bronze to an iron based society brought about many social and economic changes, including a general reevaluation of the natural world. The science of other civilizations such as Babylon and Egypt percolated over a long period into the Greek philosophy, eventually forming a 'natural philosophy'. This philosophy was a general ordering of knowledge that was quite rational in its character. In the important Ionian trade center of Miletos located on the coast of Asia Minor, where the cultures of the surrounding Babylonian and Egyptian civilizations commingled, this proto-science first developed. In that city about 575 B.C.E. a 'school' was founded that nurtured several early important Greek scientists. Their philosophical ideas would form the first nucleus of Greek science.

One of the earliest Greek authors who incidentally mentioned minerals is Thales of Miletos,[28] who wrote that iron ores may be found in Lydien. Believing that it was alive because it attracted iron, he described the magnet as having a soul.[29] This may be the earliest record of the magnet, which is a natural form of the mineral magnetite. Thales also believed that the most important principle of the universe was water. Unfortunately no writings of his have survived.

A follower of Thales was Anaximandros[30] who wrote a prose work *On Nature* (Περι Ω υσεσ) circa 546 B.C.E., which only survives in fragments. The later Greek writer Theophrastus who had a copy of the book available, says Anaximandros considered philosophy as a principle of all things indefinite.[31] No writings of his have survived.

Anaximenes[32] followed Anaximandros idea of the non-limited in quantity but gave it a definite quality that he called 'air' or 'breath'. He was not thinking of air in the current sense but as an invisible quality that became visible only when it combined with fire, water, or earth. He thought that air with fire condensed to form clouds, water, earth and stones, with decreasing density formed. Air was in constant motion providing unexpected combinations.

Recording the ideas and philosophies of these early thinkers was also paramount to developing a true scientific approach. The adoption and reworking by the Greeks of an alphabetical writing system first developed in Asia Minor about 1200 B.C.E. made it possible to preserve and distribute within their society all manner of information. Perhaps among the first information recorded were the popular narratives that were a staple of the Greek oral tradition of singers. These tales copied and recopied countless times into new manuscripts have passed through the ages, preserving some of the earliest results of human thought.

The best of these preserved stories are the epic poems attributed to Homer[33] who flourished about 1000 B.C.E. Homer's books known as the *Iliad* (Ιλιαδ) and the *Odyssey* (Οδυσσεια)[34] are called the "Greek miracle" because these magnificent poems mark the beginning of European literature. Being as they are a history of warfare in Greece, they

[28] Thales [c624-c548 B.C.E.] was an Ionian, with possibly some Phoenician ancestry. He is considered one of the founders of Greek science and philosophy. He traveled extensively for a long period in Egypt, where he learned their mathematics and astronomy.

[29] Partington, *History of Chemistry*, 1971, **1**, pt. 1, p. 6-7.

[30] Anaximandros of Miletos [610-c545 B.C.E.], an Ionian, was a pupil of Thales.

[31] Partington, *History of Chemistry*, 1971, **1**, pt. 1, p. 7-8. • Sarton, *Introduction to the History of Science*, 1927, **1**, p. 72.

[32] Anaximenes of Miletos [*fl.* 546 B.C.E.] was an Ionian philosopher.

[33] Homer is considered the greatest epic poet of Greece. He may be a composite of several persons, but if he lived at all, he was likely a European Greek rather than Ionian, because he lived in the ninth century B.C.E., before Asia Minor was colonized. He is also said to have been blind. *Refs.* Sarton, *Introduction to the History of Science*, 1927, **1**, p. 52-56.

[34] The *editio princeps* of the *Iliad* and the *Odyssey* was published in Florence in 1488 by Demetrios Chalcondylas. There are thousands of other editions, translations, abstractions, and commentaries published since then. The English translation by A.T. Murray of the Iliad and Odyssey in four volumes of the Loeb Library, London, 1919-25 is very useful.

implicitly contain descriptions of the earliest accounts of knowledge and craftsmanship in Europe. They are full of magic and romance, containing much on social life, that is at once superstitious and moral, and giving an account of the beginning of urban life and culture. Subordinately, the poems also contain references to gems and other stones that were either incidental to the story or important elements. They provide the earliest record of the knowledge possessed by the ancients with regard to minerals and the mineralogical content of these remarkable literary works have been the subject of studies.[35]

The silver ores of Laurium (Λαυριου) located in the southern region of Attica, were known from very early times, perhaps even prehistoric, but were first developed into mines by the Greek state about 483 B.C.E., and exploited for some time afterward.[36] The ancient shafts and tools recovered from the site have provided valuable insight into ancient mining techniques. But the economic importance of the minerals recovered from these mines was substantial, as it provided a large revenue to the Athenian government. Being state property that was partitioned among the capitalist citizens, the mines were worked exclusively by slaves. Sometime after 480 B.C.E., the revenue was diverted to build a fleet of ships that gave naval supremacy to Athens. It is also possible that portions of the money financed the building of some of the famous marble architecture of the city. By the last half of the first century B.C.E. the mines were exhausted and the tailings were being reworked, and by the second century C.E. the mines were no longer exploited.

Pythagoras[37] may have been one of history's greatest thinkers, but it is difficult to say how much of what is attributed to him is authentic. He flourished about 530 B.C.E. and is sometimes seen as a man of science, and at other times a disciple of mystic ideas. Legends attached to his name at an early time and it is now impossible to say with certainty much about his life. He came from Samos and founded at Kroton, a Greek colony in southern Italy, a brotherhood including woman that was a combination of religion, science, and community. It was viewed with suspicion by the surrounding community, and Pythagoras and his followers viewed with mistrust. Eventually, the group was forced to disband, with Pythagoras himself fleeing to Metapontion where he is said to have died.

A mathematical genius, Pythagoras developed techniques to solve geometrical problems. His most famous solution being called the Pythagorem theorem that says the square of the length of the hypotenuses of any right triangle is the addition of the squares of the two other sides: $a^2 + b^2 = c^2$. He is also credited with discovering the numerical ratios that determine the concordant intervals of the musical scale. Pythagoras' focus on applying rigid logic to solving real problems was revolutionary.

An important upswing in mineralogy and all other sciences occurred when problems were solved by Pythagoras application of thought and logic. The Pythagorean school viewed the cosmos as five interlocked geometric shapes, i.e., cube, tetrahedron, octahedron, icosahedron, and pentagonal dodecahedron. A viewpoint that for better or worse flowed into the following centuries. They saw the earth as an ordered unit that could be analyzed, dissected, and understood by the human mind. This conception that man could decipher the secrets of nature was the real, lasting legacy of Pythagoras and his school of thought.

In the classical age, the scientific study of minerals as it is thought of in modern terms did not exist. Instead, minerals in the classical

[35] Lenz, *Mineralogie der alten Griechen und Römer*, 1861, p. 1-6. • Aubin Louis Millin [1759-1818]., *Minéralogie Homérique; ou Essai sur les Minéraux, dont il est fait mention dans les Poëmes d'Homere*. Strasbourg et Paris, 1790. xiv, 118 p. • *ibid.*, *Minéralogie Homérique, ou Essai Sur Les Minéraux, Dont il est fait mention dans les Poèmes d'Homère*. Second edition. Paris, 1816. 8, [ix]-xviij, [2], 199, [1] p. • *ibid.*, German transl., *Mineralogie des Homer*. Königsberg und Leipzig, 1793. 22, [2], 126 p.

[36] Anonymous., "Der Bergbau und die Mineralien von Laurion, Griechland," *Emserhefte*, Halten, Germany, Bode Verlad Gmbh., **2-94** (1994), 80 p., illus. • Edouard Ardaillon., *Les mines du Laurion dans l'antiquite*. Paris, 1897. 218 p., illus. • William Kohlberger., "Minerals of the Laurium mines, Attica, Greece," *Mineralogical Record*, **7** (1978), 114-125.

[37] Pythagoras [*fl.* 532 B.C.E.] was a native of Samos, and was one of the best Greek philosophers and mathematician.

age were more the object of philosophical speculation more than laborious observation because there were at the time few aids to guide the researcher. Besides, the number of scientists or natural philosophers in Greece at the time was not large, and the majority of ideas that have managed to survive to the present show more attention to mathematically attuned studies like astronomy. Those few writings that do mention minerals are usually simple mentions of locations of ore deposits or simple descriptions of the mineral or metal under discussion. Nevertheless mineralogy as it developed in ancient Greece experienced an important upswing that was not achieved again until 2000 years later during the Renaissance.

Writing in the early eighth century B.C.E. Hesiod[38] in his *Works and Days* (Εργα και ημεραι)[39] provides descriptions of animal husbandry, naval navigation, a calendar of lucky and unlucky days, etc. Hesiod conceives of Five World Ages, four of which he characterizes by matching them to the metals, gold, silver, bronze, and iron. This idea may be Babylonian in origin but is none the less very interesting. He also references a small selection of minerals, including chalk and amber.[40]

About 440 B.C.E. Herodotos[41] authored *The Persian Wars* (Περι γομερωυ γεν–εσιωσ)[42] in nine books that contains much on science and ethnographic lore, including his first hand descriptions of a prehistoric Macedonian lake village and an account of the eclipse in the spring of 480 B.C.E. But no eclipse occurred in that year! He also gives a long discussion of the Nile river and deduced from the presence of fossilized shells that lower Egypt was once covered by the sea.[43] Scattered through out are mentions of a large variety of metals and minerals including sources for iron, copper, tin, gold, silver, ivory, and amber.[44]

Thucydides[45] writing about 404 B.C.E. mentions the lava fields of Aetna in his history of the Peloponnesian War, which he witnessed.[46] This history is a literary classic, in which Thucydides also provides a brief account of the evolution of Greek society from the earliest times to his own era.

According to Lenz,[47] Xenophon[48] writing about 330 B.C.E. mentions lead ore in his *Cyropaedia* (Κυροπαιδεια).[49] Empedocles[50] describes sulfurous gases emanating from certain areas of ground in Sicily, and was

[38] Hesiod was born in the first half of the eighth century B.C.E. in Ascra, near Mount Helicon in Boeotia. He is called the father of Greek didactic poetry. *Refs.* Sarton, *Introduction to the History of Science*, 1927, **1**, p. 57.

[39] The *editio princeps* of the *Works and Days* was published in Milan in 1493 by Demetrios Chalcondylas, and a collected edition of his works appeared from the famous Aldine press in 1495. Many other editions have appeared. One of the best in English is Hugh Gerard Evelyn-White's edition of Hesiod, *The Homeric Hymns and Homerica*. London, Loeb Classical Library, 1914.

[40] Lenz, *Mineralogie der alten Griechen und Römer*, 1861, p. 6-7.

[41] Herodotos of Halicarnassos [c484-425 B.C.E.] was a Greek historian, and is sometimes called the father of history. He traveled extensively throughout the regions of the Mediterranean, lived in Samos, then Athens during the ascendancy of Pericles. *Refs.* Sarton, *Introduction to the History of Science*, 1927, **1**, p. 105-106. • *World Who's Who in Science*, 1968, p. 789.

[42] The first printed edition was published by Aldo Manuzio in Venice in 1502. Many other renditions have been published.

[43] Geikie, *Founders of Geology*. London, 1905, p. 7, 28, 32-33 & 36.

[44] Lenz, *Mineralogie der alten Griechen und Römer*, 1861, p. 7-14.

[45] Thucydides [c460-400/395 B.C.E.], an Athenian, was one of the first historians and one of the greatest of all times. His is sometimes called the founder of scientific historiology. *Refs.* Sarton, *Introduction to the History of Science*, 1927, **1**, p. 106.

[46] Lenz, *Mineralogie der alten Griechen und Römer*, 1861, p. 14.

[47] Lenz, *Mineralogie der alten Griechen und Römer*, 1861, p. 15-16.

[48] Xenophon [c430-354 B.C.E.] was a Greek natural philosopher and historian, who was once a student of Socrates. He worked as a mercenary for the Greeks in a campaign in Persia. After a defeat he successfully directed a retreat of the soldiers back to Greece. He authored a number of works in philosophy and history. *Refs.* Sarton, *Introduction to the History of Science*, 1927, **1**, p. 122-123. • *World Who's Who in Science*, 1968, p. 1831.

[49] *Cyropaedia*. First edition, Rome, 1474. A Greek and English edition in two volumes is part of the Loeb Library, 1914.

[50] Empedocles [Agrigentum, Sicily, c490-Mt. Etna, 430 B.C.E.] was a native of a Greek colony located in Sicily. He was a follower of Pythagorean philosophy. A political leader in Akragas, he helped overthrew a tyrannical ruler, but refused the throne when it was offered. He was then exiled and he wandered through Greece and other Mediterranean regions. In his time, he was considered a prophet, miracle worker, poet, and physician. *Refs.* Sarton, *Introduction to the History of Science*, 1927, **1**, p. 87. • *World Who's Who in Science*, 1968, p. 523-524.

the first to formulate the concept of nature consisting of four basic elements: earth, water, fire, and water. This would later become a foundation concept in Plato's and Aristotle's view of the physical world.

Plato[51] was the founder of an academy in Athens whose philosophical work was not focused on the natural world. Nevertheless, his writings on chemistry and other aspects of nature including minerals were influential.[52] Plato believed that metals formed from water solidifying within the intense cold of the earth, while other minerals were created from combinations of fire and water. However, Plato's studies of minerals were very limited, and it was left to his most famous pupil to explore and expand generally on his teachers theories about nature.

### 2.12.1 Aristotle

Aristotle[53] is perhaps the most famous of the ancient scholars due to the vast scope of disciplines his writings touched upon. He was a critic of literature, scientist, and philosopher. He also had a strong interest in physical science and biology, and authored his *Meteorlogia* (Μετεωρωλωγικα) that included discussions of a number of sciences such as astronomy, geology, and seismology, besides meteorology.[54] It was typical of his age that the natural sciences were not yet differentiated into individual studies, but part of an overall natural philosophy. In this context Aristotle developed a concept of how the earth functioned.

Aristotle believed that all physical matter was created by various combinations of two natural exhalations. They were created when the sun warmed the earth.

1. Vaporous, which is cool and moist, and formed from the water and earth.
2. Windy or smoky, which is hot and dry and formed solely by the earth itself. It rises above the more watery exhalation and exists in the zone of fire.

Airs, clouds, lightning are created by the exhalations. They also combine with in the earth to make bodies. The vaporous forms the metals, including the ores, such as iron, gold, silver, and copper. The smoky exhalation forms the other minerals and fossils. These include the insoluble like realgar, ochre, and sulfur. He considered most minerals to be made of colored dust such as cinnabar. The ductile or fusible metals such as gold and copper were theorized to form by the entrapment of the vaporous exhalation, particularly within stones whose dryness compresses and solidifies.

Aristotle's model also presents heat and cold as active qualities. Heat, he said, is of three kinds: ripening, boiling, and roasting. Cold also consists of three types: rawness, scalding, and scorching. These had been used by Hippocrates in his *On Ancient Medicine*, which was perhaps Aristotle's source. The effects of heat and cold interacting with the two exhalations are said to form the whole of the physical world.

Many stones, gold, silver, copper, tin, and lead are composed of water and are melted by heat. Liquids like water, wine, urine, vinegar

[51] Plato [Athens, Greece, 427/8-Athens, Greece, 347 B.C.E.] is one of the most famous Greek philosophers. Plato was a student of Socrates, and after his execution he traveled extensively. He returned to Athens where he founded in 387 B.C.E.a school for research that is considered the first university. His writings are a staple of learning to the present time.

[52] Edmund O. von Lippmann., *Abhandlungen und vorträge zur Geschichte der Naturwissenschaften*. Leipzig, Veit, 1906-1913. 2 vols. [The volumes contain accounts of the chemical knowledge of the ancient authors.]

[53] Aristotle [Stagira, Chaldice, near Macedon, Greece, 384 B.C.E.-Chalcis, Island of Euboea, Greece, 332 B.C.E.] was the son of Nicomachus, physician to King Amynas II of Macedon. He became a student of Plato, at the Athens Academy, 367-347 B.C.E. Afterward he traveled throughout the Greek world, especially Asia Minor, 347-342 B.C.E. He was appointed by Phillip II of Macedon to be tutor to his son (later called Alexander the Great). Aristotle founded and was a teacher of the Lyceum (or Peripatos) in Athens, 335-323 B.C.E. In 323 B.C.E., he retired to Chalcis upon death of his guardian, Alexander the Great. He is the founder of the systematic study of symbols and logic and theory of symbolism which enabled him to develop logic as a science. He collected facts about the natural world around him through personal observation. These he then recorded in a series of monographs which were handed down through manuscript until the invention of printing. Aristotle, as a teacher, had great influence on his students, with his ideas and ideas attributed to him, becoming the cornerstone of western science and philosophy for one and a half millennia. *Refs.* Xxx xxxx xxxx.

[54] Bibliography ...

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are made solid by cold. Wood, bone, horn, bark, leaves, and vegetables are composed of earth in varying proportions, because some of these substances are softened by fire, while some give of fumes. Semen and blood are composed of earth, water, and air.

Homogenous bodies that include plants, animals, and minerals have passive qualities that can be used to distinguish them. Aristotle lists them as solidifiable, meltable, softened by heat or water, flexible, breakable, fragmentabale, plastic, ductile, malleable, fissible, cuttable, viscous, friable, compressible, and combustible. His distinguishing qualities thus defined, Aristotle describes the metals and non-metals.

The occasional remarks Aristotle makes in his writings about minerals and stones follow the theory of Empedokles that first theorized the four basic elements of earth, air, fire, and water that was further developed by Plato to say that the metals formed distinctive ores because of the fusibility of water inside the earth, while the non-metals were formed by earth alone. Aristotles' scant descriptions of minerals and their formation in the *Meteorologia* was in many respects the authoritative text for mineralogy for centuries afterward. His conception of minerals was left to one of his brightest students to elaborate.

### 2.12.2 Theophrastus

Aristotle's pupil, Theophrastus[55] authored a large number of works on both philosophy and science. His best know book is the *Characters* (Χαρακτηρεσ) that gives a series of vignettes of human characters probably based on Aristotle's *Ethics*. Theophrastus' *Plantis* (Περι φυτων αιτιων) and *De Lapidibus* (Περι λιθωυ) are his best known scientific works. The later work, *De Lapidibus* or *On Stones* is the oldest treatise dealing exclusively with minerals, and it is important not only in the development of mineralogy but also in the technology of chemistry.[56]

The text of *De Lapidibus* is written as a series of 69 paragraphs that suggest it is a series of lecture notes rather than a formal treatise. Some passages contain obvious additions that appear to be notes appended to the more detailed information. If true, It seems possible then that this book is a set of lecture notes as the author might have delivered them to students in the gardens of the Lyceum almost two millennia ago. Incredibly, the text of the treatise appears to have survived to the present little changed from what was originally written. All books that have survived from the ancient period have made their passage through time by a tradition of manuscript copying. Invariably, as the scribes copied and recopied manuscripts, mistakes were unwittingly introduced. The fact that *De Lapidibus* exists in only a few manuscripts that when compared show few differences, suggests that Theophrastus' work is probably very close to what was originally written.

The text gives a Peripatetic view of the origin of minerals and stones, and upon this foundation suggested by Aristotle and Plato, modifications are introduced. Metals are said to be composed of water, while stones and mineral earths are composed solely of earth. A mineral forms because its elementary substance has been purified through filtration, and its degree of purity can be determined by examining such qualities as its smoothness, density, luster, and transparency. The primary interest in the work are the descriptions of specific minerals. Theophrastus divides them into two broad categories, Earths and Stones, under which about fifty distinct 'species' are recognized. A commentary is attached to each mineral, where in the author recounts various physical properties such as texture, color, transparency, hardness, luster, and density, as well as the practical uses. Thus described, it is possible to apply modern names

[55] Theophrastus [Ereos, Island of Lesbos, Greece, c371 B.C.E.-Athens, Greece, 287 B.C.E.] studied at Athens and became an ardent supporter of Plato's philosophies. While there, he became a pupil and friend of Aristotle, and when Aristotle went into exile, Theophrastus succeeded him as the leader and principal spokesman of the Peripatetic school of philosophy—a leadership he held until his death. *Refs.* Xxx xxxx xxxx.

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to the species Theophrastus described over eighteen centuries ago, and read the Classical theories about marble, pumice, onyx, gypsum, amber, pyrite, coal, azurite, chrysocolla, realgar, orpiment, cinnabar, quartz, lapis lazuli, emerald, sapphire, ruby, and diamond.

By recording the physical properties of the minerals, this work set an high standard for other mineralogical writings. Theophrastus is in fact the first investigator to methodically treat mineral substances for themselves rather than for their magical or curative properties, and he may be considered the best and most accurate mineralogist among the ancients.

The bodies that formed in the earth owe their origin to water (the metals) and others to the earth (the stones).

The mineralogical text of Theophrastus was the most substantial written in the ancient period. Not until the time of Pliny did something comparable appear, but even that was based in part on Theophrastus. Nevertheless other ancient authorities touched upon mineralogical subjects. Apart from the philosophical explanations about the origin or composition of minerals, localities of ore deposits and mines are frequently noted. Medical uses of minerals were also an important area of study. This shows a trend toward overall accuracy.

### 2.12.3 Agatharchides

Agatharchides or Agatharchus,[57] wrote works about Asia and Europe, styled on the on the writings of Thucydides. Long extracts from a work of his about the Red Sea are contained in Photius, who appreciated the style of their writing as well as their content. He describes locations where gold sands may be recovered (placer deposits?), as well as lead, salt, and some tin.[58]

### 2.12.4 Damigeron

Damigeron[59] drew heavily on Pliny in his descriptions of stones and minerals, when he composed his second century c.e. poem, *De Virtutibus Lapidum* (The Marvelous Stones).[60] In his list of stones that possess supernatural properties he lists rock crystal, diamond, jasper, opal, chrysolith, magnet, coral, agate, heamatite, sardoynx, and emerald. Other than the charmed properties of the stones, little other material is given to distinguish the stones. Orpheus' *Lithica* seems to draw heavily on Damigeron's lapidary.[61]

### 2.12.5 Diodorus Siculus

A native of Sicily, Diodorus Siculus was a Greek historian who authored his *Bibliotheca Historica* (Historical Library)[62] in Greek that is thought to have consisted of 40 books, but which parts of only 15 have survived. It gives a history of the world from its creation to about 60 b.c.e. Lacking any overall arrangement of the descriptions, it is nonetheless a valuable collection of materials from many sources that are now lost. Among his commentary, he gives occasional notes to traveler's that touch upon mineral topics. Some of the most interesting passages are quotations from Agatharchides on mining in Egypt and the recovery of tin in the British Isles. He also covers Arabia, Ethiopia,

[57] Agatharchides of Cnidus, was a Greek historian and geographer, who lived in the time of Ptolemy Philometor (181-146 b.c.e.) and his successors.

[58] Adams, *Birth and Development of the Geological Sciences*, 1938, p. 21-22. • Lenz, *Geschichte der Griechen und Römer Mineralogie*, 1861, p. 29-31. • Sarton, *Introduction to the History of Science*, 1927, **1**, ??-??.

[59] Damigeron ...

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[60] *Damigeron et varii ethnicæ vetustatis scriptores de virtutibus lapidum*, (**3**, pp. 324-335), in: J.B. Pitra, ed., *Cardinal. Spicilegium Solesmense*, 1855. [BL, 3622.c.2.]. • Damigeron., *De virtutibus lapidum. The virtue of stones. Attributed to Damigeron.* Translated by Patricia P. Tahil. Edited by Joel Radcliffe. Seattle, Ars Obscura, 1989. vii, 75 p., illus., notes. • R. Halleux and J. Schamp., *Les lapidaires grecs. Lapidaire orphique, kérygmes lapidaires d'Orphée, Socrate et Denys, lapidaire nautique, Damigéron-Evax.* Paris, Les Belles Lettres, 1985. xxxiv, 349 p., notes.

[61] Adams, *Birth and Development of the Geological Sciences*, 1938, p. 32. • Mieleitner, *Geschichte der Mineralogie*, 1922, p. ??-??. • Sarton, *Introduction to the History of Science*, 1927, **1**, ??-??.

[62] The first print editions were in Latin, 1472, and in Greek in 1539; the first translation into English was by Thomas Stocker, London, 1568, and later by G. Booth, 1700. ...

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India, describing large animals, plants, and stones. Common of the time, he believed that rock crystal is pure water that has been frozen to rock by heavenly forces. Emerald and aquamarine derive their colors directly from heaven while topaz receives its color from the sun. He records that amber is found around the islands of the north (probably in the Baltic sea), and that it floats on the water there. In Babylon he describes asphalt where it is used as a building material, and describes the alkali waters of the dead sea, which are bitter to the taste. Locations around the Mediterranean and the Near East where precious and other ornamental stones are recovered are noted, as are metal mines.[63]

### 2.12.6 Dioscorides

The Greek physician Pedanius Dioscorides[64] is famous for his *De Materia Medica*[65] in five volumes which enumerates the plant, animal, and mineral pharmaceutical preparations he used in his medical practice. It appeared between 50 and 70 c.e., and became the model for all modern pharmacopoeias, because it focused on the manufacture, properties, and testing of drugs. As was the case with many Greek medical texts, *De Materia Medica* was treated as dogma for many centuries, and in fact Dioscoride's text remained a valuable addition to any physician's library until about 1600.

To write his reference, during his lifetime, Dioscorides traveled extensively seeking medicinal substances from all over the Roman and Greek world. He benefited greatly from the ease of travel across wide stretches of territory under the control of the Roman Empire at the height of its growth. Furthermore, he had access to a large number of medical manuscripts. To some extent Dioscorides and Pliny appear to have used the same sources for their descriptions, put Pliny's treatment is the better of the two. Dioscorides' work also has some minor additions from Arabian and Indian sources.

The fifth book of the *De Materia Medica* deals with wine and minerals, and chapters 84 to 185 contain Dioscorides' descriptions about one hundred different preparations derived from minerals.[66] In addition to most of the substances known before, he, so far as can be identified, adds schist, cadmia (blende or calamine), chalcitis (copper sulphide), misy, melanteria, spry (copper or iron sulphide oxidation minerals). He describes the making of certain artificial products, such as copper oxides, vitriol, litharge, pompholyx, and spodos (zinc and 1 or arsenical oxides). His principal interest for us, however, lies in the processes set out for making his medicines.

### 2.12.7 Strabo

The later Grecian writer Strabo,[67] in his seventeen volume *Geography* (GREEK),[68] gave full descriptions of all parts of the known world. Writing in Greek about 7 c.e., his fascinating pictures of the history and geography of the Roman territories or the 'Inhabited World' as it was known at the time, is particularly interesting for the descriptions of the geo-political landscape during the early years of the Roman Empire. This was the time

[63] Adams, *Birth and Development of the Geological Sciences*, 1938, p. 22-23. • Lenz, *Geschichte der Griechen und Römischen Mineralogie*, 1861, p. 32-38. • Sarton, *Introduction to the History of Science*, 1927, **1**, ??-??.

[64] Pedanius Dioscorides [c40 in Anazarbus, Cilcia - c90] was an ancient Greek physician who worked in the Roman empire. He was a pharmacologist and botanist who practiced in Rome at the times of Nero. He was a surgeon with the army of the emperor so he had the opportunity to travel extensively seeking medicinal substances from all over the Roman and Greek world. *Refs.* John M. Riddle., *Dioscorides on pharmacy and medicine*. Foreword by John Scarborough. Austin, University of Texas Press, 1985. xxviii, 298 p., illus. • *ibid.*, "Dioscorides," (pp. 1-143) in: P.O. Kristeller and F.E. Cranz, eds., *Catalogus translationum et commentarioum: Medieval and Renaissance Latin Translations and Commentaries*, **4**, Catholic Univiversity of America Press, Washington, 1980.

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[66] Adams, *Birth and Development of Geological Sciences*, 1938, p. 23-24. • Lenz, *Mineralogie der alten Griechen und Römer*, 1861, p. 67-79.

[67] Biography ...

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[ ]*Refs.* Sarton, *Introduction to the History of Science*, 1927, **1**, p. ??-??.

[68] Bibliography ...

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in which the emperors Augustus and Tiberius prevailed, and as a historian Strabo recorded the final collapse of the Roman Republic and its replacement with the Roman empire.

In his great work, Strabo frequently mentions mines and minerals, with his greatest interest directed to the silver mines located in Spain, and then under Roman control.[69]

### 2.12.8 Physiologos[70]

The *Physiologos* or *Physiologus* is a kind of bestiary containing descriptions after a fixed plan for each animal, plant or stone: a Biblical account, then the 'wonder' stories, and finally the allegorical-mythical interpretation. It was supposed to have been written in Alexandria but the original was more likely composed about 254-380 c.e. in Caesarea, perhaps by a Palestinian Jew under Syrian influences. The basis was a zoological work of the First Century c.e., which was also used by the author of the *Kyranides*. It contains many ideas showing Middle East and Oriental influences, particularly with regard to the magical, mystical and superstitious character of the natural objects described. Works such as the *Physiologos* were regarded as important in the early Christian Church for explaining nature through the Bible, although its references to magic contained in magic Indian stones, agates detecting pearls, the magnet, male and female igniting and ignitable stones, and the diamond, caused the Church of later centuries concern.

Written in Greek, the original *Physiologus* (Greek for "The Naturalist") described the characteristics of animals and birds-both real and fantastical-and provided allegorical interpretations of the characteristics enumerated. It has been described as a "kind of naturists scrapbook" containing a compilation of animal description, lore, and myth. Accreted to it through the years were descriptions of other natural objects including plants and stones, as well as Biblical citations. In short, the *Physiologus* is best described as the "great sourcebook of Christian nature symbolism," in which nature is not treated as an object of scientific study, but as a metaphor for Christianity and for God. For instance, the Eagle soaring to the sky and plunging into a cool well becomes an allegory for baptism, while the descent of the lion from the hilltop becomes an allegory for Christs descent to Earth. In this sense, visibilia (animals) were thought to reflect invisibilia (God).

With its diverse roots in Eastern Mediterranean lore, Classical natural history, Judeo-Christian exegesis, the *Physiologus* became immensely popular all over the world and was subsequently translated into a diversity of languages: Ethiopian, Armenian, Syriac, Arabic, Latin, Russian, Flemish, Provencal, Old English, Middle English, Icelandic, and many others. It has been said that no other book except the Bible has ever been so widely distributed among so many people and for so many centuries as the *Physiologus*.

### 2.12.20 Xenocrates

A lapidary authored by a certain Xenocrates appeared during the time of Nero in the first century c.e. Incidental evidence in citations from this work contained in Pliny's *Natural History* indicates that the author was still alive in 77 c.e. Lost in time the actual author is somewhat of a quandary.

Pliny in the list of works he has cited in writing his *Natural History* indicates in his first book that a Xenocrates Zenonis is the source for books 34, 35, and 37, and a Xenocrates Ephesius as a source for books 12 and 13 on botanical matters. However, since Pliny also quotes a Xenocrates Ephesius as an authority on rock crystal in his book 37, it seems that these citations refer to the same Xenocrates and may be combined to form Xenocrates, the son

[69] Adams, *Birth and Development of the Geological Sciences*, 1938, p. 25-27. • Lenz, *Geschichte der Greichen und Römischen Mineralogie*, 1861, p. 49-67.

[70] Other information may be found in: Karl Ahrens., *Zur Geschichte des sogenannten Physiologus*. Ploen, 1885. • *ibid.*, *Buch der Naturgegenstände*. Kiel, C.F. Haeseler, 1892. 84 p. [A Syriac version of the *Physiologus*, with German translation. "Textverbesserungen von Prof. Dr. G. Hoffmann".] • F.N.M. Diekstra., "The Physiologus, the Bestiaries, and Medieval Animal Lore," *Neophilogus*, **69** (1985), no. 1, 142-155. • *Isis*, **14** (1930), 428. • M.R. James., "The Bestiary," *History*, **26** (1931), 1-11. • Krumbacher, *Geschichte Byzantinischen Litteratur*, 1897, p. 874-877. • Friedrich Lauchert., *Geschichte des Physiologus*. Strassburg, Karl J. Truebner, 1889. 328 p. • Partington, *History of Chemistry*, 1971, **1**, pt. 1, 248-249. • Sarton, *Introduction to the History of Science*, 1927, **1**, 300. • Thorndike, *History of Magic*, **1**, p. 490.

of Zenon, from Ephesos. Ullmann believes that this was the author of the lapidary Pliny cites.

Other authorities such as Wellmann and Wirbelauer believe that the author refered to was a Greek physician, who worked during the first century of the Roman period, Xenocrates of Aphrodisias, who flourished circa 70 C.E. in Rome.[71] He wrote books on food and drugs, especially interesting for their recitation of many ancient superstitions and occult remedies, however, most of these survive only in fragments or are incorporated in other extant works. He is blamed by Galen for making use of strange remedies invloving human brains, flesh, liver, urine, excrement, etc. Perserved by Oribasius, his *De Alimento ex Aquatilibus* gives an interesting record of the state of natural history during his time. The first edition of this book was printed in Greek with a Latin translation by Bishop Janus Dubravius, and published in 1559.[72] There were three later editions that are revised and better texts by J.G.F. Franz (Francofurti, 1779),[73] A. Conray (Neapoli, 1794),[74] and A. Koraes (Paris, 1814).[75]

Whoever the actural author may have been, the *Lithognomon* (Λιθογνωμων) of Xenocrates is a typically synthetic work that combines mineralogical knowledge of different sources and of different centuries.[76] It includes in the stone descriptions a variety of details including color, action of light, size, and other characteristics of appearance. Localities are noted and include countries like Italy, Spain, Sicily, Greece, Cyprus, Libya, Egypt, Arabia, Syria, and India. Uses to which the stones are put are mentioned. Xenocrates also makes plentiful use of magical properties and superstitions especially in his discussions of the medical uses of the stones that mostly originated in eastern lapidaries. It was extensively copied and quoted by contemporary and later authors, such as the fore mentioned Pliny, who Wellmann thinks derived his catalog of gems in Book 37 directly from Xenocrates. Julius Solinus in his third century *Collectanea Rerum Memorabilium*, Damigeron in the fifth century *De Virtutibus Lapidum*, and Isidor of Sevilla in Book 16 of his late sixth century *Etymologie* probably also made use of the *Lithognomon* in their treatment of stones and minerals. Thus the text was widely available during the Middle Ages.

Although the complete text of Xenocrates still existed in Byzantium in the 13th century, it is today lost. Therefore, identifying the text of the stone book has been only a relatively new development. The most recent research has been done by Ullmann, who identified and reconstituted portions of the original text using several early lapidary manuscripts.[77] This amounts to only about 14 long quotations and other fragments from the *Lithognomon* that

[71] Biographical information may be found in: Hazel, *Who's Who in the Greek World*, 2000, p. ??. • Michaud, *Biographie Universelle*, **??**, p. ??-??. • Smith, *Dictionary of Greek and Roman Biography*, 1849, **3**, p. 1294.

[72] Janus Dubravius [c1486-1533]., *De piscinis et piscium qui in eis aluntur naturis libri quinque ... Item Xenocratis De alimento ex aquatilibus Graece & Latine nunc primum aeditus, cum scholiis Conradi Gesneri.* Zürich, 1559. [14], 136 p.; [69] p., illus.

[73] Xenocrates, of Aphrodisias, edited by Johann Georg Friedrich Franz [1737-1789]., *Peri tes apo enydron trophes.* Cum Latina interpretatione I.B. Rasarii et Conradi Gesneri scholiis animadversionibusque illustravit atque glossarium adiecit G.F. Franzivs. Francofurti, 1779.

[74] *ibid.*, *Xenocratis De alimento ex aquatilibus, cum latina interpretatione Jo. Bapt. Rasarii, scholiis Conradi Gesneri, & notis integris Jo. Friderici Franzii.* Accedunt novae variantes lectiones ex codd. mss. depromtae, & animadversiones Diamantis Coray nunc primum editae; itemque adnotationes in auctorem, additamenta in glossarium Franzii hodiernam ichthyologiam illustrantia, & lucubratio de piscium esu Caietani de Ancora. Neapoli, Typis Regiis, 1794. xlviii, 266, [2] p.

[75] *ibid.*, edited by Adamantios Koraes [1748-1833]., *Xenokratous kai Galenou Peri tes apo ton enydron trophes Hois prostepheintai semeioseis kai ta peri tes ekdoseos prolegomena.* Parisioi, I.M. Everartos, 1814. [4], xl, 245, [1] p.

[76] Additional information may be found in: Meier, *Gemma Spiritalis*, 1977, p. 62-63. • Meyer, *Geschichte der Botanik*, 1855, **2**, p. 55-58. • Partington, *History of Chemistry*, 1971, **1**, pt. 1, p. 189. • Sarton, *Introduction to the History of Science*, 1927, **1**, p. 261. • Manfred Ullmann., *Natur und Geheimwissenschaften im Islam*, 1972, p. 10-11 and p. 98-100. • *ibid.*, "Xenokrates," (cols. 974-977) in: Georg Wissowas, ed., *Paulys Realencyclopädie der Classischen Alterumswissenschaft.* München, 1974, supplement, vol. **14**. • Max Wellmann., "Xenokrates aus Aphrodisias," *Hermes*, **42** (1907), p. 614-629. • *ibid.*, *Die Stein und Gemmenliteratur des Altertums*, 1935, p. 102-104.

[77] Manfred Ullmann., "Das Steinbuch des Xenokrates," *Medizinhistorisches Journal*, **7** (1972), p. 49-64. • *ibid.*, "Neues zum Steinbuch des Xenokrates," *Medizinhistorisches Journal*, **8** (1973), p. 59-76.

have been perserved in other works.

### 2.12.21 Galen

Galen[78] was authored a large number of books (some sources say 500), many of which are still extant as either fragments or complete treatises. He was an authority in many fields medical including anatomy, physiology, embryology, pathology, therapeutics, and pharmacology. With respect to mineral studies, he focused on the pharmaceutical uses to which minerals and stones could be applied. In his *De Simplicium Medicamentarum Temperamentis et Facultatibus* (Simple Medicines),[79] together with medications prepared from plants and animals, he describes ointments and remedies made from various minerals; however, little appears to be original to Galen in his mineral prescriptions, with the recipes being repeated from earlier authorities, such as Dioscurides.[80]

## 2.14 The Roman Period[81]

The Roman Empire developed in the first century B.C.E., and covered the entire land mass surrounding the Mediterranean including the ancient civilization of Greece and its various colonies. However, the Romans lacked the versatility, many-sidedness and imaginative power of the Greeks. These were qualities imported from the Greeks and elsewhere, where scientific study, especially medicine was still studied. The eminent qualities of the Romans are sober and acute thought, and firmness and perseverance of will. Their intellect was directed to the practical, and sometimes degenerated into egotism and cunning, just as their perseverance often turned into obstinacy and pedantry. In the domain of state and law these qualities accomplished great and enduring results, while they were decidedly unfavorable to art and literature. This is generally seen in their scientific thought. Few theoretical studies are recorded by the Latin writers. Their bent is towards practical applications. The preeminent scientific writer among all ancient Roman writers on mineralogy is, as in so many other subjects, is of course, Pliny. In fact, except for some few lines by other Latin authors, there is practically little else in extant Roman literature of technical interest, for the metallurgical metaphors of the poets and orators were threadbare by this time, and do not excite so much interest as upon their first appearance among the Greeks and Hebrews.

### 2.14.1 Lucretius

The Roman Lucretius[82] composed about 57 B.C.E. his *De Rerum Natura* (On the Nature of the Universe), a philosophical poem of epic proportions.[83] When he died

[78] Galen (born in Pergamum 129; died at the age of 70), anatomist, physician, philosopher, was the greatest physician of antiquity after Hippocrates. He dissected numerous animals, but very few human bodies; discovered a large number of new facts in the fields of anatomy, physiology, embryology, pathology, therapeutics, pharmacology. He made various physiological experiments, e.g., to determine the mechanism of respiration and pulsation, the function of the kidneys, of the cerebrum, and of the spinal cord at different levels. He proved experimentally that arteries contain and carry blood; that it suffices to divide even a small artery to drain away all the blood of the body in half an hour or less;' that the right auricle outlives the rest of the heart. He gave a semirational (physiological) interpretation of dreams and had some notion of their medical interest. His chief merit consists in having systematized and unified Greek anatomical and medical knowledge and practice. He was a very prolific, clear, and vigorous writer. *Refs.* Xxx xxxxxx xx xxx xxxx. Xxx xxxxxx xx xxx xxxx. Xxx xxxxxx xx xxx xxxx. Xxx xxxxxx xx xxx xxxx. Xxx xxxxxx xx xxx xxxx.

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[80] Adams, *Birth and Development of the Geological Sciences*, 1938, p. 49. • Partington, *History of Chemistry*, 1971, **1**, pt. 1, p. 192-200. • Lenz, *Mineralogie der alten Greichen und Römischen*, 1861, p. 116, 179. • Sarton, *Introduction to the History of Science*, 1927, **1**, p. ??-??. • Thorndike, *History of Magic*, 1923, **1**, p. 125-132.

[81] For further information on Roman science generally see: Sarton, *Introduction to the History of Science*, 1927, **1**, throughout the volumes.

[82] Titos Lucretius Carus (Born: c99; Died: 15 October 55 B.C.E.) was a Roman poet and the author, but nothing else is certain of his life.

[83] Facsimiles of the two fundamental manuscripts, both of the ninth century and both kept in Leiden, have been published, with introductions by Em. Chatelain, *Codex Vossianus oblongus.* Leiden, 1908.; *Codex Vossianus quadrates.* Leiden, 1913. • *Editio princeps*, Brescia (c1473). • First scientific edition, Lachmann (1850) and elaborate commentary by the same (3d ed., Berlin, 1868; 4th ed., 1871). • H.A.J. Munro, *De Rerum Natura.* 3 vols., 4th ed., London, 1905-1910. [Vol. I, Text; Vol. II, Notes; Vol. III, English translation. A full account of earlier editions will

the composition was left unfinished but the beauty of the poetry nevertheless quickly made the work very popular throughout the Roman Empire. Its style is sincere and earnest, and the verse is written in good Latin. As a result, the text, except for a few lines, has survived to the present day in a nearly complete form.

This epic undertakes a full and completely naturalistic explanation of the physical origin, structure, and destiny of the universe. It is an amazing account of the positive knowledge of his time (Greek knowledge of course) and of the atomic theory, together with a few prophetic views (e.g., vague anticipation of the theory of natural selection). Lucretius's chief purpose was to suppress superstition by elevating deduction through reason. In all of science, including mineralogy, Lucretius' theories on the atomic structure of matter and the evolution of life formed basic ideas from which much of western philosophy and science gained inspiration until the late Renaissance.[84]

### 2.14.2 Vitruvius

Marcus Vitruvius[85] is the author of the famous treatise *De Architectura* (On Architecture), which is divided into 10 books. Contrary to what the title might suggest the work is not simply a comprehensive treatise on architecture but is also an encyclopedia of building technology during the Roman era, as well as a cornucopia of scientific knowledge. He discussed sound as a vibrating motion in the air, gives the earliest formula for hydraulic cement, and describes the importance of hygiene and regular bathing.

With respect to rocks and minerals Vitruvius discusses at great length the virtues and problems of various building materials including marble, limestone, and granite. He gives information on quarrying methods and locations where the most suitable rock can be found. He also knows that rocks have different strengths, which should be taken into account in building design. Vitruvius also discusses a variety of mortars and cements, the mineral materials required for each of their manufacture, and what application each is best suited for.[86]

### 2.14.4 Seneca[87]

Lucius Annaeus Seneca[88] was the leader of Stocism in Rome. His *Naturales Quaestiones* (Natural Questions) are a collection of questions and answers on matters related to the natural and physical sciences from the atomistic viewpoint.[89] Only seven books of the

be found in Vol. I]. • *Lucretius, Epicurean and Poet.* London, 1907-1909. 2 vols., 710 p. [This is the most elaborate study available; it deals with the life and times of Lucretius, his philosophic ideas and scientific knowledge, their sources, and their influence in later times down to our own.] • William A. Merrill's edition with introduction and notes (New York, 1907) is also excellent.

[84] John Masson., *The Atomic Theory of Lucretius, Contrasted with Modern Doctrines of Atoms and Evolution.* London, 1884. 264 p. • Partington, *History of Chemistry*, 1971, **1**, pt. 1, p. 138-148. • Sarton, *Introduction to the History of Science*, 1927, **1**, 205-206.

[85] Marcus Vitruvius Pollio (born ca 80/70 BC?; died ca. 25 BC) was a Roman writer, architect and engineer, active in the first century B.C.E. Little is known about his life. Even his first name Marcus and his cognomen Pollio are uncertain. They are only mentioned by Cetius Faventinus. Most data about his life are extracted from his own work. He was born as free Roman citizen, most likely at Formiae in Campania. He is believed to have served in the Roman army in Spain and Gaul under Julius Caesar. He was probably one of the army engineers, constructing war machines for sieges. In later years he was employed by his sponsor, the emperor Augustus, entitled with a pension to guarantee his financial independence. His date of death is unknown, which suggests that he had enjoyed only little popularity during lifetime. *Refs.* B. Baldwin., "The Date, Identity, and Career of Vitruvius," *Latomus*, **49** (1990), p. 425-434. • DSB, **15**, p. 514-521. • Indra Kagis McEwen., *Vitruvius: Writing the Body of Architecture.* New York, MIT Press, 2004.

[86] Adams, *Birth and Development of the Geological Sciences*, 1938, p. 35-36. • Lenz, *Mineralogie der alten Greichen und Römischen*, 1861, p. 40-46. • Sarton, *Introduction to the History of Science*, 1927, **1**, p. ??-??.

[87] Thomas G. Rosenmeyer., "Seneca and Nature," *Arethusa*, **33** (2000), no. 1, p. 99-119. • Martin von Schanz., *Geschichte der römischen Litteratur bis zum Gesetzgebungswerk des Kaisers Justinian.* München, 1904-1935, §???.

[88] Lucius Annaeus Seneca (Born: Cordova, Spain, 4 B.C.E.; Died: 65 C.E.) was a Roman writer, philosopher, the leader of Stoicism in Rome, statesman, and scientist.

[89] Editio princeps (Naples, 1475). Critical edition in 4 vols. by Hermes and others (Leipzig, 1898-1907; Vols. I-III republished 1905-1914; vol. II contains the Naturalium quaestionum libri VIII (only 7 books are extant) edited by Alfred Gercée, 326 p., 1907). English translation by John Clarke, with notes by Sir Archibald Geikie (422 p., London, 1910. Particularly interesting from the geological and meteorological standpoint). • Christian Beyer, et al., "Die Naturales Quaestiones von Lucius Annaeus Seneca. Eine kommentierte Bibliographie," *Nachrichten aus dem Institut für Geschichte der Naturwissenschaften, Mathematik*

complete work are extant, and most of that is given over to celestial phenomena. Book 1 discusses 'lights' or fires in the atmosphere; Book 2, lightning and thunder; Book 3 concerns bodies of water. Seneca's method is to survey the theories of major authorities on the subject at hand and his work is therefore a rewarding guide to Greek and Roman thinking about the heavens. Book 4 discusses hail and snow; Book 5, winds; Book 6, earthquakes; and Book 7, comets. It is a work of philosophical—rather than scientific—remarks about natural phenomena. It offers no great originality but gives an insight into ancient theories of cosmology, meteorology, and similar subjects. He is also the first writer to express belief in the progress of knowledge.

His *Quaestiones Naturales* are a collection of physical, astronomical, geographical, geological, and meteorological questions explained from the atomistic point of view. They contain hardly anything which is really original, but exerted a great influence throughout the Middle Ages. Special mention must be made of his account of the earthquake which did much damage in Campania on February 5, 63-the earliest detailed account of an earthquake. This led him to discuss earthquakes and volcanic phenomena. He distinguished three kinds of motion in quakes (succussio, inclinatio, and vibratio). Seneca was the first to express a belief in the progress of knowledge (not the progress of humanity); this idea of progress is unique in ancient literature. Earlier monographs of Seneca on India and Egypt and on earthquakes are lost.[90]

Seneca was one of the most important and prolific writers of his day, both in prose and in verse. Ten books of ethical essays (miscalled 'Dialogi) survive on subjects such as anger, the constancy of the Stoic sage, and tranquillity of mind. Three of them are consolationes to the bereaved. He presented to Nero, early in his reign, a treatise called De Clementia in which he commended this quality to the autocrat. It is possible that Shakespeare had it in mind when composing Portias great speech on the quality of mercy. He also wrote the De Beneficiis in seven books. His Naturales Quaestiones, eight books on physical science, achieved great popularity. The Epistolae Morales of which 124 survive give philosophical and ethical advice to a friend. He is almost certainly the author of the Apocolocyntosis, a bitter satire on the deification of Claudius. Seneca also wrote nine tragedies on Greek mythological subjects, designed to be recited or read rather than acted. They are somewhat melodramatic and violent ,and had an influence on Elizabethan and Jacobean tragedy in England out of all proportion to their merits.

### 2.14.5 Cato[91]

The Roman statesman, moralist, and farmer Marcus Porcius Cato, or Cato the Censor was born at Tusculum, 234 b.c.e., and died in Rome in 149 b.c.e.. He wrote in his old age a treatise on farming, gardening, fruit-growing, etc. *De Agriculture* that was the first book on the subject in Latin. It also contained valuable information on Roman medicine (empirical and magical). He was violently opposed to Greek medicine and philosophy. Among the facts incidentally quoted by Cato, is the earliest mention for ordinary mortar and the earliest description of a bain-marie.

In the *De Re Rustica* cement, calx, silex, breccia and salt are mentioned. Cato also describes methods for extracting salt from sea water.[92]

Cato the Censor is so called to distinguish him from his equally illustrious great-grandson, Cato of Utica. As the latter is one of the noblest figures of Roman times and will not be mentioned elsewhere in this Introduction,

*und Technik*, Hamburg, **22** (1992), 22-35.

[90] Adams, *Birth and Development of the Geological Sciences*, 1938, p. 47-8. • Geikie, *Founders of Geology*, 1905, p. ?? • Lenz, *Mineralogie der alten Greichen und Römischen*, 1861, p. 47-48. • Partington, *History of Chemistry*, 1971, **1**, pt. 1, p. 166. • Sarton, *Introduction to the History of Science*, 1927, **1**, p. ??.

[91] Adams, *Birth and Development of the Geological Sciences*, 1938, p. 48. • Lenz, *Mineralogie der alten Greichen und Römischen*, 1861, 28-29. • Sarton, *Introduction to the History of Science*, 1927, **1**, p. ??.

[92] Lenz, *Mineralogie der alten Greichen und Römischen*, 1861, 28-29.

it is proper to say a few words about him in this place. Born in 95, bred as a Stoic, leader of the aristocratic party ultimately defeated by Caesar, his political career was outwardly a succession of failures, but he gave such admirable proofs of moral strength and virtue that his life will ever remain a source of inspiration. In 46, his task being accomplished, he committed suicide at Utica (hence his name in order not to fall into the hands of Caesar. Cicero, Caesar, and Plutarch have told and discussed his life.

Ed. Thrämer: Cato Censorius and die Griechenmedizin (Mitteil. zur. Gesch. d. Medizin, t. 14, p 404-405 1915. A short note to point out that the medical ideas which Cato opposed to the Greek ideas were probably also of Greek origin).

### 2.14.7 Pliny[93]

Plinius Secundus, perhaps better known by the modernized Pliny the Elder was born in Nova Coma, Italy in 23 or 24 b.c.e. At an early age he was sent to Rome for his education. He eventually entered the military service. His career is only known in general outline, but Pliny probably served during the Germanic Wars, of which he wrote a now lost 20 book history. He came to the attention of the Emperor and was appointed to a succession of administrative posts in territories of present day Spain, Germany, France, and north Africa. At the end of his civil career Pliny was made commander over the Roman fleet stationed at Misenum. From there he set out to witness firsthand the major volcanic eruption of Mt. Vesuvius located near the bay of Naples. While observing the eruption he got too close and was as suffocated by the vapors from the eruption. He died near the volcano at Stabiae in August, 79 c.e.

Pliny must have been one of the most widely read scholars of antiquity, as well as its most industrious researchers, because he held the opinion that no book was so poor that it did not yield something of interest. His nephew and editor, Pliny the Younger, in his *Epistolae* preserves an interesting sketch of his uncle, saying that he was in his leisure continuously reading. Even during meals and baths books were read aloud to him. Throughout his long and distinguished career he was always accompanied by his own large library, and an even larger collection of excerpts he had copied from books he did not own. A stenographer was always nearby so that any dictation Pliny wished to give was recorded. Even though he lead a very busy and active life, Pliny was able through great focus to collect a large number of 'facts' that allowed him to write a large number of works, but of which only one has survived.[94] It is said that in the middle of his life, he was offered a princely sum of money for his library and excerpts, but that he could not part with his treasure. Instead Pliny extended it with further excerpts. The nephew records in his *Epistolae* that after his uncle's death more than 160 complete books were found in his library. Certainly, these were the foundation references for Pliny's greatest and single surviving work.

Pliny set as a goal to compile an encyclopedia of the entire range of natural science. So broad would his treatment be in the *Historia Naturalis* that even none obvious studies like medicine, art and geography would be represented. By 77 c.e. the work had come to a conclusion of sorts, with his material categorized into thirty-six books. Adding a foreword in which the contents of the other books are given, Pliny presented the work to Titus, so that in essence the work was complete in thirty-seven books. In the original layout, the list of sources for each of the books was given at the start of each book. This was contrary to many other ancient authors that concealed what sources they used. In fact, in his foreword Pliny openly expresses his debt to the authors from whom he copied his material. Soon after he presented the volume, Pliny was appointed commander of the fleet. However, he apparently continued to add new material to the work up to his unexpected death. The nephew, Pliny the Younger, inherited all of his uncle's literary compositions, including the

[93] Other information may be found in: Martin von Schanz., *Geschichte der römischen Litteratur bis zum Gesetzgebungswerk des Kaisers Justinian.* München, 1904-1935. [Article, "Plinius Secundus", §490.]

[94] Lost books

*Historia Naturalis*. The nephew, did some superficial editing of the manuscript, probably making only a structural change that collected together all of the original sources into a single list that was placed at the end of the foreword in the first book. The remainder of the work maintained its original structure of thirty-six books, and that is how the text has come down to the present.

| | |
|---|---|
| Book | Description and foreword. |
| 1 | Table of contents and list of sources. |
| 2 | Mathematical and physical description of the world. |
| 3-6 | Geography. |
| 7 | Anthropology and physiology of man. |
| 8-11 | Zoology. |
| 9 | Fish. |
| 10 | Birds. |
| 11 | Insects. |
| 12-27 | Botany. |
| 28-32 | Medical zoology. |
| 33-37 | Mineralogy, especially applied to life and art. |

The enterprise that Pliny dedicated himself to was certainly large. Nobody before him, including any of the Greeks, had attempted what Pliny executed. Only an iron will and great diligence could create such a grandiose work, the single most comprehensive compendium of science that exists from ancient times. The author read and excerpted many authors indeed for his extraordinary book; however, this activity was exhausting. No time remained for him to think about what he was copying into his *Historia Naturalis*. Therefore, a deeper understanding or even mild criticism in the material Pliny presents is absent. All his facts have an equal weight, regardless of how fabulous the claim. It is a work that can be regarded only as a compilation.

Pliny himself says the book contains some 20,000 facts collected from 2,000 works by 100 select authors, the most important single source being Varro. These numbers are, however, undercounted since no fewer than 146 Roman and 327 foreign authors are cited in the text. He includes everything with no attempt to verify even the most outlandish and improbable 'facts'. Thus he appears to be more of an avid cataloger rather than a modern scientific researcher. Yet, his work is one of the most valuable that has survived from the classical period because it quotes works and authors that are today only known from their inclusion in the *Historia Naturalis*. This is true of Pliny's treatment of mineralogical topics as well.

From no other ancient writer do we have as much mineralogical data as we do from Pliny, and probably this fact has over emphasized his contribution to ancient mineral studies. Next to Theophrastus, however, Pliny gives the most important mineralogical information of the ancient period, and after it appearance little in the way of important scientific mineralogical data are giving in antiquity. The works of the following centuries describe minerals almost exclusively from their occult or medical value, which although interesting provide no real scientific value.[95]

The influence Pliny's encyclopedia exerted in later times was immense. It was often copied in whole with a substantial number of early manuscripts still survive. It was also the principle source for two other later works: Solinus' *Collectanea Rerum Memorabilium* of the middle third century, later used by Isidore of Seville, and the so called *Medicinia Plinii* from the start of the fourth century that excerpted and rearranged Pliny's medical information. In addition the encyclopedists of the Middle Ages frequently drew on Pliny for their material.

### 2.14.8 Suetonius

The most important literary character of his time, Suetonius[96] compiled among other works, a miscellany, called the *Prata* (Meadows) that dealt chiefly with Roman antiquities and natural sciences (laws, customs, winds, seas, animals, plants, and minerals), of which only a small fragment is extant. Unfortunately, nothing of its mineralogy survives.[97]

[95] Lenz, *Mineralogie der alten Greichen und Römischen*, 1861, p. 79-173. • Sarton, *Introduction to the History of Science*, 1927, **1**, p. 249-251. • Teuffel, *History of Roman Literature*, 1892, §312.

[96] Caius Suetonius Tranquillus (Born: c75 C.E.; Died c160 C.E.) was a Roman historian and polygraph.

[97] Sarton, *Introduction to the History of Science*, 1927, **1**, p. 284. • Teuffel, *History of Roman Literature*, 1892, §347.

### 2.14.9 Solinus

In the third century, the Roman grammarian and historian Caius Julius Solinus[98] compiled his *Collectanea Rerum Memorabilium* (Collection of Curiosities) that contains a broad description of the ancient world, with many remarks on the natural history, religion, and social issues of his time.[99] Solinus does not name his sources, but the greater part of the text, which is arranged on a geographical plan, is mainly derived from Pliny's *Natural History* and the geography of Pomponius Mela.

The author begins his work with a very valuable section that gives a description of the mythical prehistory of the establishment of the Roman Republic by Romulus after the Etruscan rulers were conquered. He continues the history to the time of Augustus. A general treatise on humanity follows that treats the peoples of Italy, Greece, Germania, Gallica, Britannia, and Hispania, the last also has details of northern Africa. Asia, Arabia, Egypt, Syria, the Near East, and India are also described. The author wanted to maintain the readers attention and therefore paid special attention to the peculiarities of the people and places discussed. Solinus peppers his commentary with anecdotal information about the land, animals, plants, and minerals of the various regions. Descriptions of several dozen precious stones, which come from Pliny, are interspersed throughout the work with placement under the countries where the stones are supposed to be found. Later, in the sixth century, these stones would be collected together again by Isidore of Seville for inclusion in Book XVI of his *Etymologiae*.

A revised version of the original text appeared in the sixth century. This version includes at the start a letter purportedly from Solinus that acts as an introduction. In it, the work is awkwardly renamed *Polyhistor seu de Mirabilibus Mundi* (Multi-History of the Wonders of the World). Throughout the Middle Ages both versions of the text circulated widely and in some cases 'Polyhistor' was taken for the author's name. The broad sweep of its coverage made it a popular manual of its subject, and as a result the book had tremendous influence during the Middle Ages, being, for example, a principle source for Isidore of Seville. An important commentary on this work by Claude de Saumaise appeared in his *Plinianae Exercitationes* (1689). The best edition edited by Th. Mommsen was published in 1895; it contains a valuable introduction to the extant manuscripts, the authorities used by Solinus, and the subsequent compilers.[100]

## 3.0 Medieval Mineralogy[101]

The dethroning of the last Roman emperor Romulus Augustulus in 476 c.e. marked a political end to the age of antiquity. From the scientific viewpoint however, a definitive border between the Classical Age and the Middle Ages can not readily be drawn because the literature between the periods is indistinguishable. In particular, studies related to mineralogical questions are usually short, sometimes being only mere mentions, and commonly contained in longer, more general literary works. The classical authorities such as Aristotle and Theophrastus dominate the era with their ideas reworked time and again throughout the age. Nevertheless the studies carried on from the Classical period and nurtured during

[98] Add Biographical References.

[99] Many incunabula his editions the first being probably that of Venice, 1473 (there are at least two undated editions which may be earlier). Critical edition by Th. Mommsen (Berlin, 1864; revised 382 p., 1895). English translation by Arthur Colding (1587).

[100] Meyer, *Geschichte der Botanik*, 1855, **2**, p. 249-252. • Sarton, *Introduction to the History of Science*, 1927, **1**, p. 341. • Claude de Saumaise., *Plinianae Exercitabones in Solini Polyhistora*. Paris, 1629 (also 1689). [Contains a criticism of Solinus.] • Schanz, *Geschichte der römischen Litteratur*, 1904, **4**, 1. • Teuffel, *History of Roman literature*, 1892, p. 389.

[101] The development of mineralogy in the Middle Ages has been treated in several interesting essays: Adams, *Birth and Development of the Geological Sciences*, 1938, chap. 4. • Evans, *Magical Jewels*, 1922. • Friess, *Edelsteine im Mittelalter*, 1980. • Christel Meier, *Gemma spiritalis. Teil I.* München, Wilhelm Fink Verlag, 1977. 542, [2] p., biblio. • Karl Mieleitner., "Zur Geschichte der Mineralogie. Geschichte der Mineralogie im Altertum und im Mittelalter," *Fortschritte der Mineralogie*, **7** (1922), 427-480. • J.U. Nef., "Mining and metallurgy in Medieval civilization" (**2**, pp. 430-492) in: *Cambridge economic history of Europe*. Cambridge [Eng.]; New York, The University Press, 1952.

the Middle Ages would lay the foundation of mineral science that would begin to flourish in the Renaissance.

## 3.1 Islamic Influences

At the end of the Classical age, eastern Europe and most notably Alexandria were the center of scientific activity; however, this predominance would soon be destroyed by the rise of a new and at first persecuted sect of Christians.[102] In 389 C.E. the Serapion of Alexandria was burned, and its library destroyed or scattered under an edict calling for the destruction of all pagan temples within the Empire—an order administrated with great enthusiasm and severe cruelty. In the same year, important schools at Edessa were closed, with the banished teachers taking refuge in Asia Minor. The Museum of Alexandria, actually a university, maintained an uncertain existence until 415 C.E. when the Christians incited riots that caused the last remnants of the Alexandrian schools of philosophy and science to be swept from Europe, thus tossing the region into an intellectual pallor.

With the suppression of the schools and the teachers of the ancient science scattered, scientific achievement in the Christian countries stagnated for centuries. Ancient Greek thought with its foundation in logic became almost forgotten. What speculation there was on nature was centered on harmonizing first hand observations with the Scriptures or with prevailing Church doctrine. So devoid of any scientific achievement were the early centuries of Christian Europe, it is probable that the science developed by the ancients, except for a few of its practical applications, would have been lost to western civilization had it not been preserved in the Near and Middle East.

In contrast to Europe where the intellectual activity was confined to the cloister of the monastery, the Arabic schools founded at Baghdad, Damascus, Alexandria, Cordova, and Seville after the Moslem conquests of the Middle East, North Africa, and Spain provided a true scientific light during this otherwise dark period. In these institutions the traditions of the ancient pagan schools and their literature were maintained and cultivated especially by the Syrian scholars who had taken refuge in Persia after the closing of the Alexandrian schools. Through these scholars, the classical works of Plato, Aristotle, Theophrastus, Galen, Dioscorides and others, were preserved and translated into Syrian. Since these individuals also occupied influential positions as astronomers, mathematicians, physicians and engineers within the government, the manuscripts of Greek and Alexandrian authors were subsequently translated into Arabic and Persian. Thus Arabians and Persians became in medieval times the best trained scholars in science and medicine.

As the Mohammedan conquest swept west along the African coast from Egypt to Spain, the ancient books of Aristotle, Theophrastus, Dioscrides, Galen, Pliny, Epiphanius, Homer, Pythagoras, etc. followed. This preserved wisdom had also been considerably augmented by original Arabic research. Thus to the forthcoming European Renaissance a large body of apparently new scientific literature became readily available. In fact, so completely had the original ancient writings disappeared from the Europe of the Middle Ages that at first these works were all thought to be original Arabic texts rather than ancient Greek writings transmitted by translation through the centuries. In the history of mineralogical and chemical science in Europe therefore, Arabian influence is of importance because it was through this channel that the ancient texts were reintroduced to latinized Europe.

### 3.1.1 Islamic Mineralogy

The history of mineralogy in Islam has been documented by a number of researchers, and it is through their essays that the western world has come to know the influence of the middle east on western mineralogy.[103] Many of

[102] For further information, see: Sarton, *Introduction to the History of Science*, 1927, **1**, p. ??-??.

[103] J. Clement-Mullet. *Essai sur la Mineralogie Arabe ... basee sur le traite de Teifaschi [al-Tifashi] (?-651/1253); Suivi de: Recherches sur l'histoire naturelle ... chez les Arabes*. Paris, 1868. • A. Mieli. *La science arabe et son rôle dans l'évolution scientifique mondiale*. Leiden, 1966. xix, 467 p. • al-Rawi, M.M., "Geology and mineralogy," (4, pt. 2, pp. 405-424) in: al-Hassan, A.Y., et al., editors, *Science and Technology*

those Islamic writings were never translated into western languages, but because their authors frequently quoted one another, those mineralogical works that did make their way to Europe had at their roots the ideas of many Arab researchers.

Crystallographic properties were unknown in the mineral studies of the Islamic Middle Age. Instead common physical properties were used to distinguish stones. These characters included color, smell, taste, texture, breakability, friability, malleability, solubility in water, etc. Sometimes but particularly in alchemical writings the behavior of a stone in acid or fire was referenced. With respect to the medical applications of stones the elementary Aristotelian qualities of hot, cold, damp, and dry were particularly important. As remedies, stones were either laid on the patient or pieces pulverized and the powder mixed with water, milk or oil and the resulting mixture either ingested by the patient or used as an ointment applied to an infection or burn. Instances of mineral powders used as makeup or as poisons are also recorded.

Keeping with Aristotelian philosophy, Islamic authors believed water, air, and earth were components of all minerals, while fire was the regulator of the other three. Plants and animals it was also believed, contained these same components in so far as their material composition was concerned. Every mineral contained earth as its body, water as the spirit, and air as the soul, which are all combined and balanced by fire. Using these principles minerals were divided into seven classes:

1. Stoney, but fusible and solidifying on cooling. Examples include gold, silver, copper, iron, tin, lead, glass, etc.
2. Stoney, but not fusible, included diamond, hyacinth, cornelian, etc.
3. Earthy, soft, not fusible, but easily separated and friable. Such as various salts, talc, vitriols, etc.
4. Watery and evaporating in fire defined quicksilver (mercury).
5. Aerial or oily that is consumed by fire, includes sulfur, arsenic, etc.
6. Vegetable-like, form like a plant and includes coral, etc.
7. Animal-like, were derived from animals such as pearls.

The common metals gold, silver, copper, lead, tin, iron were thought of as minerals of a special type. They are made up of the same basic four elements but also included mercury and sulfur in their composition. Differences between the metals were thought to arise from various proportions and purities of mercury and sulfur in the metal. Because of their fusibility, their ability on cooling to regain a solid state, the fact that they could be melted together to form other alloys, their malleability and their adaptability to so many uses like jewelry, coins, statues, tools it was thought that the metals possessed a composition more alike to each other than was the case with minerals in general. However, there was no philosophical distinction between minerals and metals. For example, glass melts and resolidifies to a hard mass, and when heated it is also malleable and ductile, thus giving rise to the notion that glass was another type of metal, which is the reason why it is occasionally listed with them by some medieval writers. Frequently electrum and bronze or brass are described as separate metals, even by authors who know they are alloys of other metals. On the other hand, mercury is usually not listed with the metals eventhough it is known to alloy or amalgamate with other metals.

From the 9th to the 17th centuries, many Islamic authors touched upon mineralogical subjects like precious stones or metallurgy. Few of these works were ever translated or for that matter printed, and exist to the current time only in manuscript versions. Nonetheless, the

*in Islam*. Beruit, 2001. • Ruska, J., "Die Mineralogie in der arabischen Literatur," *Isis*, **1** (1913-14), 341-350. • Steinscheider, M., "Arabische Lapidarien," *Zeitschrift deutscher morgenländischer Gesellschaft*, **49** (1895), 249-272. • Steinscheider, M., "Lapidarien, ein culturgeschichtlicher Versuch" (pp. 42-72) in: Kohut, G.A., ed., *Semitic studies in memory of Rev. Dr. Alexander Kohut*. Berlin, 1897. • Ullmann, M., *Die Natur- und Geheimwissenschaften im Islam*. Leiden, 1972. xiii, 500 p. • Wiedemann, E., "Zur Mineralogie bei den Muslimen," *Archiv für die Geschichte der Naturwissenschaften und der Technik*, **1** (1909), 208-11. • Wiedemann, E., "Beiträge zur Geschichte der Naturwissenschaften XXX. Zur Mineralogie in Islam," *Sitzungsberichte der Physikalisch-medizinischen Sozietät in Erlangen*, **44** (1912), 205-256.

works listed below provide a substantial view of these writings.

### 3.1.2 Jābir ibn Ḥayyān [*Latin*, Geber]

Abū Mū sā Jābir ibn Ḥayyān al-Azdī [*Latin*, Geber] (*died* 803 c.e.) is perhaps the most famous alchemist of the Middle Ages.[104] He practiced medicine and alchemy in Kufa, Iraq, about 776 c.e., and established his reputation as one of the leading scientists of Islam. Supposedly, he is the author in Arabic of a very extensive library of alchemical and other scientific books, but by no means could he be the author of all works attributed to him. It is now recognized that many of the writings are the work of a school rather than an individual.[105]

These alchemical works provide remarkably reasoned descriptions of the methods of chemical research, and they show knowledge of the usual chemical reactions such as calcination, crystallization, reduction, solution, sublimation, which are often described. There is a statement of the sulfur/mercury theory of metals and descriptions of the preparation of a large number of chemical substances, including basic lead carbonate and the reduction of arsenic and antimony metal from their native sulfides. The methods are practical and include processes for the creation of steel and the refinement of the metals, or creating dyes and varnishes. Coloring agents for glass are also indicated. Jābir is credited with several discoveries including the manufacture of nitric acid, sal ammonic, ammonium chloride, hydrochloric acid, nitrate of silver, etc. But to the alchemists and chemists of the Middle Ages, the descriptions and illustrations of furnaces in Jābir's books were probably of even greater value.

### 3.1.3 *pseudo*-Aristotle

The authority of Aristotle's name during the Middle Ages was held in such great esteem that many titles appeared that pretended to be authentic books of the master, but were in fact much later efforts. Two such *pseudo* works that touched upon minerals appeared in the ninth century. It has been shown that both texts were originally written in Syriac and subsequently translated into Latin and other languages. Each in their own way would have a significant impact on the mineral studies of the Middle Ages.

With its origins anchored in traditional 6th century natural history texts like the *Physiologus*,[106] the *Lapidary of Aristotle* written no later than the 9th century is very likely a compilation cast in a Greek framework from Syriac and Persian sources (many of the stone names are Iranian), rather than an actual work of Aristotle.[107] Because it

[104] DSB, **7**, 39-43. • *Encyclopedia of Arabic Literature*, **??**, ??. • *Encyclopedia of Islam*, **2**, 357-9. • Kraus, P., *Jabir ibn Hayyan: contribution à l'histoire des idées scientifiques dans l'Islam. Jabir et la science grecque*. Paris, Belles Lettres, 1986. xv, 406 p. [Originally published as vol. 2 of a 2 vol. work under same title, Le Caire, 1942.] • Sarton, *Introduction*, 1928-52, **1**, p. 532-534.

[105] Haq, S.N., *Names, natures and things: the alchemist Jabir ibn Hayyan and his Kitab al-Ahjar (Book of stones)*. With a foreword by David E. Pingree. Dordrecht, Kluwer academic publishers, 1994. xx, 284 p. [Published as: *Boston Studies in the Philosophy of Science*, **158**.] • Geber, *The works of Geber*. London, 1678. Reprinted, London, 1928, with introduction by E.J. Holmyard and R. Russell. Reprinted, Kessinger Publishing, 1990. • Berthelot, M., *La chimie au moyen Age*. Paris, 1893. [Where vol. 3, L'alchimie arabe, contains the Arabic text of a few of Jabir's writings edited by Otave Houdas and a French translation, p. 126-224.] • Darmstaedter, E., *Die Alchemie des Geber*. Berlin, 1922. [German translation of the Latin treatises ascribed to Geber.] • Holmyard, E.J., "Arabic chemistry," *Nature*, **110** (1922), p. 573. • Holmyard, E.J., "Jābir ibn Ḥayyān," *Proceedings of the Royal Society of Medicine*, Historical Section, **16** (1923), 46-57. [An elaborate study together with a *catalogue raisonné* of Jāir's texts.] • Kraus, P., "Studien zu Jābir ibn Hayyān," *Isis*, **15** (1931), 7-30. • Kraus, P., *Jabir ibn Hayyan: contribution à l'histoire des idées scientifiques dans l'Islam. Jabir et la science grecque*. Paris, Belles Lettres, 1986. xv, 406 p. [Originally published as vol. 2 of a 2 vol. work under same title, Le Caire, 1942.] • Mieli, *La Science Arabe*, 1966, p. 55-59. • Steinscheider, *Arabische Lapidarien*, 1895, p. 247. • Stillmann, *Story of Early Chemistry*, 1924, p. 185-189.

[106] Ahren, Karl, *Das Buch der Naturgegenstände*. Herausgegeben und übersetzt von K. Ahren. Kiel, C.F. Haeseler, 1892. viii, 84 p.; 71, iii p. [Containing a Syriac version of the *Physiologus*, with a German translation. Sarton draws the conclusion that this is the basic publication that led to the *Lapidary of Aristotle*].

[107] Sarton, *Introduction*, 1928-52, **1**, 572. • Stillman, *Story of Early Chemistry*, 1924, p. ?????? • Thorndike, *History of Magic*, 1923-58, **2**, 260ff. • Ullmann, M., "Der literarisches Hintergrund des Steinbuches des Aristoteles," (pp. ??-??) in: *Actas IV Congresso de Estudos Árabes e Islâmicos*, Lisboa, 1968. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 105-110. • Wellmann, M., "Aristoteles de Lapidibus," *Sitzungsberichten der Preussian Akademie der Wissenschaften. Philosophie Klasse*, 1924, 79-82. • Wiedemann, *Mineralogie in Islam*, 1912, p. 206.

is one of the oldest authorities in Arabian mineralogy, it was a dominate sourcebook in its subject during the Middle Ages. Translated by scholars at various times into Hebrew, Arabic and Latin, the texts would serve either directly or indirectly later writers, especially the encyclopedists Bartholomaeus Anglicus, Isidore and Vincent de Beauvis. The German orientalist and mineralogist Julius Ruska, using the Arabic translation supposedly prepared by Serapion the Elder in the 9th century, prepared a heavily commented German translation that appeared in 1912.[108] Previously, Valentin Rose had published a Latin text preserved in Lüttich that was a 14th century copy of a manuscript edited with additions by a pre-12th century Spanish-Arabian writer.[109]

The book, which catalogs 72 stones, minerals and jewels, gives a summary of their more obvious physical characteristics, their medicinal values and their supposed supernatural properties. This is of special value as it gives a view into the mineralogy of the Arabs of the time, which would subsequently have an important influence on the development of mineralogy.

The second work attributed to Aristotle that first appeared by the 9th century was the *Kitāb Sirr al-Asrār* whose Latin translation prepared by Roger Bacon in c1257 under the title *Secretum Secretorum* became well known in medieaval Europe. It is a compilation from Persian, Syriac and Greek sources of the late Antiquity, and it deals primarily with the occult properties of various substances, especially minerals.[110] The work is fully described under §3.5 Books of Secrets.

A very different work, the *Lapidarius* of 1473 was the first lapidary printed after the invention of mechanical printing. It is sometimes attributed to Aristotle being called the "Lapidarius et Liber de Physionomia de Aristotle,"[111] but was composed long after he lived because the text refers to authorities such as al-Rāzī and Albertus Magnus. It is a work entirely devoted to precious stones, "written in honor of Wenzel II, King of the Bohemians" (1266-1305). Furthermore, the manuscript is preserved in Switzerland as a 15th century anonomous physiognomy in the Public Library at Bern (MS. 513), and is entirely different in character from the texts published by Julius Ruska and Valentin Rose.

### 3.1.4 al-Kātib

One of the oldest known and still existing Muslim lapidaries is by ʿUṬĀRID IBN MUḤAMMAD AL-KĀTIB and has the title *Ḳitāb manāfi ʿal-ahjar* or *Kitāb al-jawāhir waʾl-ahjar* (Book of Different Jewels).[112] Written in the 9th century, it treats precious stones but apparently has never been published in modern times or critically studied.

### 3.1.5 Māsawaih [*Latin*, Mesuë the Elder]

The christian physician ABŪ ZAKARĪYĀ YŪḤANNĀ IBN MĀSAWAIH [*Latin*, MESUË THE ELDER] (*died* 857/8)[113] authored a manuscript in Arabic on minerals and gemstones under the title *Kitab al-Jawāhir wa-ṣifātihā wa-ṣifat al-ġawwāṣīn wa-t-tujjār* (The Book of Precious Stones and their Properties).[114] It was one of the earliest important Arabic works on these subjects relied upon by al-Kindī and al-Bīrūnī in compiling their own books. Māsawayh gives descriptions of twenty-four minerals and gemstones including some of their physical properties such as color, hardness and lusture, together with their localites and market value.

[108] Ruska, J., *Das Steinbuch des Aristoteles*. Heidelberg, Carl Winters Universitätsbuchhandlung, 1912. 214 p.

[109] Rose, V., "Aristoteles 'De lapidibus' und Arnoldus Saxo," *Zeitschrift für deutsches Altertum und deutsche Literatur*, **18** (1875), 321-455.

[110] Brockelmann, *Arabischen Literatur*, 1943, p. **1**, p. 282 & Suppl. **1**, p. 432. • Haskins, C.H., *Studies in Medieval Science*, 1924, p. 137-140. • Sarton, *Introduction*, 1928-54, **1**, p. 556-557. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 110-111.

[111] Lapidarius.—Quomodo virtutes pretiosorum lapidum augmentantur. — Physiognomia. Merseburg, [anonymous printer, probably Lukas Brandis], 20 October 1473. 40 ℓ.

[112] Brockelmann, *Arabischen Literatur*, 1898, p. **1**, p. 243. • Levey, M., "Arabic mineralogy of the tenth century," *Chymia*, **12** (1967), p. 17. • Ritter, *Orientalische Steinbücher*, 1935, p. 3. • Ruska, *Grieschischen Planetendarstellungen*, 1919, p. 24-26. • Sarton, *Introduction*, 1928-52, **1**, 572. • Steinschneider, *Arabische Lapidarien*, 1895, p. 249-250. • Steinschneider, *Intorno ad Alcuni Passi d'Opere*, 1871, p. 275.

[113] Sarton, *Introduction*, 1928-52, **1**, p. 574.

[114] Steinschneider, *Arabische Lapidarien*, 1895, p. 248. • Ullmann, *Natuwissenschaften im Islam*, 1972, p. 114.

Included in the descriptions are diamond, pearl, quartz, amber, amethyst, ruby, garnet, agate sulfur and turquoise. A modern study of this work has been prepared.[115]

### 3.1.6 al-Kindī [*Latin*, Alkindus]

Ya ʿqūb ibn Isḥāq al-Kindī [*Latin*, Alkindus] (*died* c870 c.e.) is the so-called "Philosopher of the Arabs" being the first and perhaps only great philosopher of that race.[116] He was a polymath with considerable knowledge of Aristotle and other Greek authorities, and his tremendous intellect is readily displayed by the diverse subjects on which he authoritatively wrote including mathematics, astrology, physics, music, medicine, pharmacy, and geography. However, few of the reported 270 books he authored are extant. Many Arabic translations from Greek originals were also prepared under his supervision.

In mineralogy, al-Kindī contributed several works. His four books that described the use of Hindu minerals are now lost, and the two works of his that have survived are only known today from manuscript fragments and short quotations in other mineralogical books.[117]

1. *Risāla fī Anwāʿ al-jawāhir aṭ-ṭamīna wa-gairihā* (Treatise on Various Types of Precious Stones and Other Kinds of Stones).

2. *Risāla fī Anwāʿ al-ḥijāra wa-l-jawāhir wa-maʿādinihā wa-jaiyidihā wa-radīʾihā wa-aṭmānihā* (Treatise on Various Types of Stones and Jewels).

### 3.1.7 al-Jāḥiẓ

Abū ʿUthmān ʿamr ibn Baḥr Al-Jāḥiẓ (c776-868/9) was the author of over 200 works on politics, religion, and science of which only thirty have survived.[118] His *Kitab al-maʿādin wa-l-qaul fī jawāhir al-arḍ* (Book of Minerals and a Report concerning Precious Stones of the Earth) written in 847 c.e. is lost. However a short description of the work is preserved.[119]

This book distinguishes the separate type of ores and metals by their reaction in fire. Information is provided on segregating false gems from true and the basic physical properties such as color to describe the minerals.

### 3.1.8 ad-Dimišqī

Abū l-Faḍl Jaʿfar ibn ʿAlī ad-Dimišqī wrote the *Kitab al-Išāra ilā maḥāsin at-tijāra wa-maʿrifat jayyid al-aʿrāḍ wa-radīʾihā wa-gušūš al-mudallisīn fīhā.* The author probably lived at the beginning of the 10th century because the latest author he quotes from is al-Kindī. He describes the most important of the commercial precious stones, citing their characteristics and criteria for authenicating true stones from fake ones as well as a pricing guide.[120]

### 3.1.9 al-Dīnawarī

About the middle of the 10th century Naṣr ibn Yaʿqūb al-Dīnawarī wrote the *Kitab al-Jawāhir* (Book of Precious Stones) in Persian a text that al-Bīrūnī frequently cites.[121]

### 3.1.10 al-Rāzī [*Latin*, Rhazes]

Abū Bakr Muḥammad ibn Zakarīyyāʿ al-Rāzī [*Latin*, Rhazes] (c854-925 or 935) was the greatest practitioner of medical procedures in Islam and perhaps in the whole of the Middle Ages.[122] He successfully combined his extensive chemical knowledge with medicine, writing almost 200 treatises in medicine, science and philosophy. His enormous and important medical encyclopedia, *Kitāb al-Ḥawī*

[115] Raʾūf, A.S., *Kitāb al-Jawāhir wa-sifātuhā Youhanna ben Masawaih.* [Edited by:] Haqqaqahu wa-ʿallaqa ʿalayhi ʿImād ʿAbd al-Salām Raʾūf. Abū Zaby, al-Majmaʾ al-Thaqāfī, c2001. 114 p.

[116] DSB, **15**, ??. • *Encyclopedia of Islam*, **5**, 122-3.

[117] Sarton, *Introduction*, 1928-52, **1**, p. 559-560. • Steinschneider, *Arabische Lapidarien*, 1895, p. 248. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 114-115. • Wiedemann, *Mineralogie bei den Musliem*, 1908, p. 209-210. • Wiedemann, *Mineralogie in Islam*, 1912, p. 206.

[118] Brockelmann, *Arabischen Literatur*, 1898, p. **1**, p. 246, nr. 7. • DSB **7**, 63-5. • *Encyclopedia of Islam*, **2**, 385-7. • Sarton, *Introduction*, 1928-52, **1**, p. 597.

[119] Ullmann, *Naturwissenschaften im Islam*, 1972, p. 115.

[120] Brockelmann, *Arabischen Literatur*, 1943, Suppl. **1** , p. 907. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 115-6.

[121] Brockelmann, *Arabischen Literatur*, 1943, Suppl. **1** , p. 433. • Sarton, *Introduction*, 1928-52, **1**, p. 706. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 116.

[122] Brockelmann, *Arabischen Literatur*, 1943, **4**, 280, nr. 2. • DSB, **11**, 323-6. • Mieli, *La Science Arabe*, 1966, p. 131-3. • Sarton, *Introduction*, 1928-52, **1**, p. 609-10.

(Book of Medicine) contains besides his own perceptive observations many extracts from Greek and Hindu authors. A practical man, he experimented with specific gravity using a hydrostatic balance, and some of his chemical works picture the furnaces and other apparatus he relied upon in his experiments.

Apparently, al-Rāzī authored two works that would impact on mineralogy. The first is his famous alchemical treatise, *Kitab al-asrar* (Book of Secrets), which was his major opus on the subject.[123] Although al-Rāzī folows Jābir on many points such as dividing the metals into seven species and in its time the work was considered to be an alchemical text, the treatise really is more concerned with chemistry than alchemy. However, al-Rāzī is the first to classifiy his substances into animal, vegetable and mineral components, a structure that was copies by virtually all later writers. Al-Rāzī then provides very careful descriptions of many chemical processes such as calcination, filteration, distillation, etc., which had been written about by Jābir and others but were especially well described by al-Rāzī. These techniques would help later researchers perfect their techniques in the analysis of minerals.

The second title that al-Rāzī wrote appears to directly concern minerals. The work is known under the titles, *Kitab al-Mudḫal al-burhānī* (Introdution to the Proof of Creation) or the *ʿIlal al-maʿādin* (Treatise of Minerals).[124] The text is concerned with the formation of spirits, bodies, stones and minerals. Unfortunately, it has apparently never been published or thoroughly researched, and in fact may now be lost.

### 3.1.11 Ikhwān al-Ṣafaʾ or "Brothers of Purity"

The economic importance of minerals was a reoccurring theme in Islamic mineral studies. This was a focus of the writings of the Ikhwān al-Ṣafaʾ or "Brothers of Purity," who authored important works in mathematics, ethics, philosophy, chemistry and mineralogy.[125] Founded about 950 c.e. in Basra, Iraq, this was a society of Arabian scholars whose anonymous eclectic writings based on Plato and Aristotle appeared between 975 c.e. and 1000 c.e. Their tenth century chemical and mineralogical writings are particularly important because they summarize the Arabian knowledge prior to the mingling of Islamic and western ideas that occurred with the Muslim conquests in the eleventh and twelfth centuries. Based on the idea that the four elements of Plato and Aristotle constitute matter they are perhaps the truest statement of the original Greek and Roman ideas from which they are derived. In 1160 c.e. their works were denounced by the Mohammedan church and their manuscripts publicly burned in Bagdad.

The Ikhwān al-Ṣafāʿ dedicated the 18th Epistle of the *Rasāʾil Ikhwān al-Ṣafāʾ* (Epistles of the Brethren of Purity) to mineralogical matters. It is titled "On the Formation of Minerals" and includes some fundamental geological principles followed by several chapters on minerals and gemstones.[126] The materials are classified according to their types and origin together with full information on their physical and rudimentary chemical

[123] **Translation:** Ruska, J., *Al-Razis Buch Geheimnis der Geheimnisse, mit Einleitung und Erläuterungen, in deutscher Übersetzung, von Julius Ruska.* Mit fünf Abbildungen. Berlin, J. Springer, 1937. xiii, [2], 246 p., illus. [Published as: *Quellen und Studien zur Geschichte der Naturwissenschaften und der Medizin*, Bd. **6**.] **References:** Heym, G., "Al-Rāzī and alchemy," *Ambix*, **1** (1938), 184-191. • Partington, P.R., "The chemistry of Razi," *Ambix*, **1** (1938), 192-6. • Ruska, J., "Al-Bīrūnī's 'Steinbuch' als Quelle einer Interpolation in Rāzī's 'Kitab sirr al-asrār'," *Islam. Zeitschrift für Geschichte und Kultur des islamischen Orients*, **25** (1939), 191-3. • Ruska, J., "Al-Razi als Chemiker," *Zeitschrift für Chemie*, **1922**, 719-22. • Ruska, J., "Die Alchemie ar-Rāzī's," *Islam. Zeitschrift für Geschichte und Kultur des islamischen Orients*, **22** (1935), 281-319. • Stapleton, H.E., et al., "Chemistry in Iraq and Persia in the Tenth Century A.D," *Memoirs of the Asiatic Society of Bengal*, **8** (1927), no. 6, pp. 317-418, 2 plates. [Text in English and Arabic].

[124] *Isis*, **6** (1924), 302. [**Reference from ULLMANN**].

• Steinschneider, *Arabische Lapidarien*, 1895, p. 250. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 117.

[125] *Encyclopedia of Islam*, **3**, 1071-6. • Mieli, *La Science Arabe*, 1966, p. 128-130. • Nasr, *Islamic Cosmological Doctrines*, 1964. • Sarton, *Introduction*, 1928-52, **1**, p. 660-661.

[126] Dieterici, F., *Übersetzt der mineralogischen Abschnitte aus den Iḫwān as-safāʾ*. Berlin, 1885. [German translation of the relavent mineralogical passages. Reference from Ullmann, *Naturwissenschaften in Islam*, 1972, p. 119.] • Levey, M., "Arabic mineralogy of the tenth century," *Chymia*, **12** (1967), 15-26. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 119-120.

properites, as well as medical and mystical uses. Gemstones are classified by Ikhwān into three categories: (1) mineral gemstones that are metallic, hard and melt when heated (gold silver and copper), (2) stony gemstones are very hard and melt only with extreme heat (agate, ruby, sapphire, etc.), and (3) earthy gemstones that are soft and break easily but do not melt (talc). Other properties are used to classify minerals such as aqueous that does not burn (mercury), fatty that do burn (sulfur), botanic that resemble plants (coral), zoological that are derived from animals (pearls), etc. Ikhwān al-Ṣafāʾ believed that heat was the essence of the formation of minerals as well as the cause for minerals to change from one form to another.

### 3.1.12 Ibn Sīnā [*Latin*, Avicenna]

Abū ʿAlī al-Ḥusayn ibn ʿabdallāh ibn Sīnā [*Latin*, Avicenna] (980 c.e.-1037 c.e.) was a famous encyclopaedist, philosopher, physician, mathematician, and astronomer, and is perhaps the most renowned scientist of Islam.[127] His great many writings in prose and verse and Arabic represented a climax of medieval philosophy, but Ibn Sīnā's legacy is the clear method he had of expressing his views in his writings. Readers develop an excellent image of the ideas the author is conveying.[128]

Ibn Sīnā's great medical and philosophical encyclopaedia the *Kitab aš-Šifāʿ* (The Book of Healing) was probably begun in 1014 c.e. and completed by 1020 c.e. The text has an implied classification of theoretical knowledge subdivided, with regard to increasing abstraction, into physics, mathematics, and metaphysics, and practical knowledge such as ethics, economics, and politics. The ideas expressed roughly represented the Aristotelian tradition but are modified by Muslim theology and Neoplatonic concepts. Buried within the text are extensive discussions of his visionary ideas on the nature of minerals, and his astonishingly insightful view of geological phenomena including the formation of stones, rocks, and mountains. He also provides some ideas on how minerals should be classified, but is ruthless in denouncing the alchemists and their attempts to transmute base metals into precious ones.[129] Because these concepts were scattered through out the large *Kitab aš-Šifāʿ*, Ibn Sīnā's penetrating observations about mineralogical wonders went largely unrecognized as his invention eventhough they did become available in medieval Europe in Latin translation.

At the conclusion of the third book of the *Meteorologica*, Aristotle promises to write a book about mineral substances, Περιδιθωv, but no Greek manuscript of this work existed in the Middle Ages. However, some medieval Latin versions of the *Meteorologica* had appended to the Fourth Book an additional chapter in three paragraphs under the title, "De Mineralibus."[130] In this section the subject is masterly dealt with in a flavor very reminescent of Aristotle's other writings; however, this mineralogy was conclusively shown in 1924 to be translations of the various passages from Ibn Sīnā's *Kitab aš-Šifāʿ* and not the writing of Aristotle.[131]

[127] Afnan, S.M., *Avicenna, his life and works*. London, G. Allen & Unwin, [1958]. 298 p. • Ammar, S., *Ibn Sina Avicenne: la vie & l'oeuvre*. [Tunis], L'Or du Temps, c1992. 157 p. • DSB, **15**, ??. [**SUPPLEMENT!!!!**] • *Encyclopedia of Islam*, **3**, 941-3. • Goodman, L., *Avicenna*, London, Routledge, 1992. [A useful introduction to central features of Ibn Sīnās philosophical theories.] • Mieli, *La Science Arabe*, 1966, 102-104. • Nasr, *Islamic Cosmological Doctrines*, 1964. • Sarton, *Introduction*, 1928-52, **1**, 709-713. • Wickens, G.M., *Avicenna: scientist & philosopher, a millenary symposium*. London, Luzac, 1952. 128 p.

[128] Gutas, D., *Avicenna and the Aristotelian Tradition, Introduction to Reading Avicennas Philosophical Works*. Leiden, Brill., 1988. [An excellent account of the considerations that entered into the construction of Ibn Sīnās corpus, the book contains translations of a number of smaller texts, a careful consideration of method and sharp criticisms of, among other things, ascriptions of mysticism to Ibn Sina. This is probably the most useful guide to an engagement with the philosophers work currently available in English.] • Janssens, J.L., *An annotated bibliography on Ibn Sina, including Arabic and Persian publications, and Turkish and Russian references*. Leuven University Press, 1991. xxvii, 358 p.

[129] Ullmann, *Naturwissenschaften im Islam*, 1972, p. 122.

[130] First printed edition, *Liber des mineralibus Aristotelis*. Bologna, 1501.

[131] Holmyard, E.J., and D.C. Mandeville, *Avicennae De Congelatione et Conglutinatione Lapidum*. Paris, 1927. viii, 85 p. English translation of the passages relavent to mineralogy and geology.] • Duhem, P, "Le traité des minéraux attribué à Avicenne," *Etudes sur Léonard de Vinci*, **2** (1909), 302-309. • Holmyard, E.J., "Arabic text of Avicennas Mineralia," *Nature*, **117** (1926), 305. [This text printed in Manget's *Bibliotheca Chemica Curiosa*, Genevæ, 1702, **1**, 636 and elsewhere, is a translation of certain sections of the *Shifa*.]

### 3.1.13 al-Bīrūnī

In the 10th century Abū Rayḥān Muḥammad ibn Aḥmad al-Bīrūnī (973-*after* 1050) was born a Persian and a Shiite.[132] He had agnostic tendencies toward his religion and his anti-Arabic feelings were strongly held throughout his life. For a time he lived in India where he became acquainted with Hindu and Sanskrit literature. As a mathematician, philosopher, astronomer, geographer, and encyclopedist, al-Bīrūnī is condsidered one of the greatest scientists of Islam and perhaps one of the greatest of all time.

He wrote, in Arabic, a large number of books (*est.* 146) on geographical, mathematical, and astronomical subjects of which only about two dozen have survived to the present time.[133] His *Kitāb al-Jamāhir fi maᶜrifat al-jawāhir* (Book on the Multitude of the Knowledge of Precious Stones) is a book in which he combined the mineralogical, physical, medical and philosophical ideas and studied the subject from all these points of view.[134] Written about 1000 c.e., this remarkable text, which is several hundred pages in length is devoted exclusively to gem materials, related minerals and metals. The whole is divided into three parts, the first is an untitled introduction, the second describing precious and semiprecious stones, and the third on metals. Using material from Hellenistic, Roman, Syriac, Indian, and Islamic sources, he supplements the text with his own perceptions. Accounts are included of the physical properties of the various minerals and gems, with very extensive etymological discussions of the technical terminology in many languages and dialects, and many illustrative quotations from Arabic poetry. Locations of the principal mines and sources of raw material are listed and al-Bīrūnī provides the relative weights of metals in relationship to gold, and provides tables showing the relative prices of pearls and emeralds as a function of their size. For example, under his description of emerald he provides a description of the mines at an oasis apparently near Mount Muqattam (which is unknown today), as well as details about the color grading of crystals, tips for spotting imitations, and prices per carat. Al-Bīrūnī uses the same descriptions of minerals as al-Kīndī in this work; however, Al-Bīrūnī's work appears to have been the major source for later Muslim authors. His scientific mind set him apart from his contemporaries in that he always attempted to preform corroboration through experimentation.

This is clearly shown by the careful measurements he makes of the specific gravity of some gemstones and minerals that is al-

[132] Brockelmann, *Arabischen Literatur*, 1943, Suppl. **1** , p. 902. • DSB, *2*, 147-58. • *Encyclopedia of Islam*, **1**, 1236-8. • Mohamed Yahia Haschimi., "Die grieschischen Quellen des Steinbuches von al-Beruni," *Les Annales Archéologiques de Syrie*, **15** (1965), no. 2, p. 21-56. • Mieli, *La Science Arabe*, 1966, p. 98-101. • Said, H.M. and Khan, A.Z., *Al-Biruni (his times, life and works)*. Pakistan, Hamhard Academy, 1981. xi, 244 p., map, photos, map, biblio., index. [Modern biography of Arab scientist Abu Rayhan al-Biruni.] • Said, H.M., ed., *Al-Biruni Commemorative Volume, Proceedings of the International Congress held in Pakistan on the occasion of Millenary of Abu Raihan Muhammad ibn Ahmad al-Biruni (973-ca 1051 AD). Nov. 26, 1973, through Dec. 12, 1973.* Printed in Pakistan at the Times Press, Karachi, 1979. [4], 844 p., 10 plates. • Sarton, *Introduction*, 1928-52, **1**, p. 707-709.

[133] Khan, A.S., compiler, *A bibliography of the works of Abu'l-Raihan al-Biruni*. New Delhi, Indian Natl. Science Academy, 1982. 77 p. [A bibliography describing & annotating 183 items.]

[134] **Modern edition:** Al-Bīrūnī, *Kitāb al-jamāhir Fī maᶜrifat al-jawāhir*. Edited by F. Krenkow. [Hydaradbad, Dāᶜirat al-Maᶜārif, 1936/37]. 273, 11, 4, 51 p. [Text in Arabic]. **Translation:** Al-Bīrūnī, "The chapter on pearls in the 'Book of precious stones. Translated by F. Krenkow," *Islamic Culture*, **15** (1941), 399-421 and **16** (1942), 21-36. • Al-Bīrūnī, *Die Einleitung zu al-Bīrūnī's Steinbuch*. Mit Erläuterungen übersetzt von Takī ed Dīn al Hīlālī. Leipzig, Harrassowitz, 1941. xxi, 41 p. [Published as: *Sammlung Orientalistischer Arbeiten*, **7**.] **References:** Bromehead, C.E.N., "Kitab al-jamahir fi ma'rifat al jawahir or 'Book of the Manifold Knowledge of Precious Stones,' by others simply called 'Gems'," *Proceedings of the Geological Association*, **56** (1945), pt. 2, pp. 89-134. • Datta, B., "Al-Biruni and the origin of the Arabic numerals," *Proceedings of the Benares Mathematical Society*, **7** (1928), 15 p. • Haschmi, M.J., *Die Quellen des Steinbuches des Bêrûnî*. Bonn, 1935. 48 p. [Dissertation, Bonn University.] • Kahle, P., "Bergkristall, Glas und Glasflüsse nach dem Steinbuch von El-Bîrûnî," *Zeitschrift der Deutschen Morgenländischen Gesellschaft*, **90** (1936), 322-56. • Nasr, *Islamic Cosmological Doctrines*, 1964. • Ruska, J., "Al-Bīrūnī's 'Steinbuch' als Quelle einer Interpolation in Rāzī's 'Kitab sirr al-asrār'," *Islam. Zeitschrift für Geschichte und Kultur des islamischen Orients*, **25** (1939), 191-3. • Steinschneider, *Arabische Lapidarien*, 1895, p. 252-254. • Wiedemann, *Mineralogie in Islam*, 1912, p. 206. • On the Kitab al- Jamahir, see, G.C. Anawati, "Kitab al-jamahir fi ma'rifat al jawahir of al-Biruni," pp. 437-53, with biblio.

Bīrūnī's most important contribution to the sciences of mineralogy and gemology set forth in the *Kitab al-jamahir* are the results of specific gravity experiments with respect to gems and metals.[135] By using a receptacle of a conical form, with an overfall at the superior end. The receptacle was filled with water, and a known weight of gold dropped in, after having placed the scale of a balance under it. In this manner, al-Biruni determined the weight of the water displaced. He then repeated the experiment with all types of metals, minerals, gems and rocks. By application of these hydrostatic principles by the method of Archimedes, he records that the results obtained depend upon the temperature and purity of the water used, but he did recognize, that the smaller the density, the greater the quantity of the water displaced for the same weight.[136] His method was effective, and the values he derived for the gemstones are close to modern day values. For example, he gives the specific gravity of red spinel as 3.58, blue sapphire as 3.97 and ruby as 3.85. These values do not deviate appreciably from today's accepted values of 3.581 for spinel and 3.987 to 4.1 for corundum. The specific gravities for a total of nine gems and nine metals are tabulated.[137] In effect, he was one of the earliest practitioners of the scientific method.

### 3.1.14 al-Kāmilī

Manṣūr ibn Baʿra al-Kāmilī[138] was appointed to a commission to study and review the mint and its operation in minting the coinage of the realm. His *Kitab Kašf al-asrār al-ʿilmīya bi-dā aḍḍarb al-miṣrīya* written in the 13th century is a manual in 17 chapters describing all aspects of minting.[139] He describes the production, cleaning, alloying of gold and silver, assaying of the metals purity, and construction of furnaces. It was a highly scholarly work providing many technical terms and is considered one of the best books of its type.

### 3.1.15 al-ʿArabī

The 17th chapter of Muḥyī al-Dīn ibn al-ʿArabī's (*died* 1240) *Kitab at-Tadbīrāt al-ilāhīya fī išlāḥ al-mamlaka al-insānīya* describes the "human characteristics of stones." He recounts the physical and mystical properties of a variety of stones including emerald, sapphire, Hyazinth, etc.[140]

### 3.1.17 al-Tifāšī

Born in 1184, Abū l-ʿAbbās Aḥmad ibn Yūsut ibn Aḥmad al-Tifāšī (*died* 1253)[141] first learned about precious and semiprecious stones from his father, and increased his knowledge by reading Aristotle, Theophrastus, Pliny, and other Islamic authorities, as well as seeking out first hand experience. Over the course of his life he made repeated trips to the localities where the stones were mined and also to the most important gemstone trading centers. In his old age he recorded all of this accumulated knowledge in his *Kitab Azhār al-afkār fī jawāhir al-aḥjār* (Best thoughts on the Best of Stones).[142] In this work 25 stones

[135] Wiedemann, E., "Arabische specifische Gewichtsbestimmnungen," *Annalen der Physik*, **20** (1883), 539-41. • Wiedemann, E., "Über das al-Berunische Gefäss zur spezifischen Gewichtsbestimmung," *Verhandlungen der deutsche physikalische Gesellschaft*, **10** (1908), 339-43. • Wiedemann, E., "Verbreitung der Bestimmungen des spezifischen Gewichtes nach al-Beruni," *Beiträge 31, Sitzungsbericht Erlangen*, **45** (1914), 31-34.

[136] Said, H.M., ed., *Al-Biruni Commemorative Volume*, 1979, p. 450.

[137] Mieli, *La Science Arabe*, 1966, p. 101.

[138] Holmyard, E.J., "Mansūr al-Kāmily," *Archeion*, **13** (1931), 187-90.

[139] Ullmann, *Naturwissenschaften im Islam*, 1972, p. 124.

[140] Brockelmann, *Arabischen Literatur*, 1943, **1**, p. 441 & Suppl. **1**, p. 790. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 124.

[141] Brockelmann, *Arabischen Literatur*, 1943, **1**, 652 & Suppl. **1** , p. 904. • DSB, **13**, ??.

[142] **Translations:** Rau, S.F.J., *Specimen Arabicum continens descriptionem et excerpta libri Achmedis Teifaschii de gemmis et lapidibus pretiosis, quod publice defendet Sebaldus Fulco Ravius.* Traiecti ad Rhenum, Apud Abrahamum à Paddenburg, 1784. 103, [1] p. • Rainieri, A., *Fior di pensieri sulle pietre preziose di Ahmed Teifascite opera stampata nel suo originale Arabo, colla Traduzione Italiana appresso, e diverse note di Antonio Rainieri.* Firenze, Nell'Imp. ER. Tipografia Orientale Mediceo-Laurenziana, 1818. [62], 118 p. [Reprinted by Count Camillo Rainer Biscia, Bologna, L. Andreoli, 1906.] • Clement-Mullet, J., *Essai sur la Mineralogie Arabe ... basee sur le traite de Teifaschi [al-Tifashi] (?-651/1253); Suivi de: Recherches sur l'histoire naturelle ... chez les Arabes.* Paris, 1868. • A modern translation of al-Tifāšī's book, *Arab Roots of Gemology: Ahmad ibn Yasuf Al Tifaschi's Best Thoughts on*

are fully described by physical properties like relative hardness, lusture and geometric form. Speculation on the cause of gem formation within the earth is given by al-Tifāšī as well as descriptions of the "mother-rock" from which the stones are extracted.

### 3.1.18 Naṣīr al-Dīn al-Ṭūsī

Naṣīr al-Dīn al-Ṭūsī (*died* 1274)[143] authored a very worthwhile work concerning precious stones and metals in the Persian language, *Tansūḫ-nāme-i īlḫānī*.[144] It is a manuscript known it two distinctive recensions. The first chapter handles 41 different precious stones including sapphire, emerald, diamond, ruby, turquoise, and jasper. The second chapter provides descriptions of precious substances of non-mineral origin including ivory, balsam, and ebony. The third chapter provides information on substances that emit odor including ambra, aloe, sandlewood. The final section describes the fusible minerals, which includes gold, silver, copper, tin, lead and the like. This work was designated the most useful and comprehensive work of its kind.

### 3.1.19 al-Qazwīnī

Abū Yaḥyā Zakarīyā ibn Muḥammad ibn Maḥmūd al-Qazwīnī (c1203-1283) was a famous Arab cosmographer and georgrapher who seems to have received a legal education.[145] A Persian writing in Arabic, al-Qazwīnī has justifiably been called the Medieval (or Muslim) Pliny, a comparision made because of the depth of his knowledge and the lack of critical temper in his books. He authored two large compendiums, which have sometimes been characterised as two parts of the same work, but which are in fact independent of each other.

The first of his books commonly called the *Cosmography* has the title *ʿAjāʾib al-Makhlūḳāt wa-jarāʾib al-mawjūdāt* (Marvels of Created Things and Miraculous Aspects of Things Existing).[146] This text is the first systematic description of cosmography in Islamic literature. That it enjoyed tremendous popularity is shown by the large number of surviving manuscripts that represent several different recensions of the text as well as early translations into Persian and Turkish. This work is divided into two parts the first of which treats celestial items and the other terrestrial ones. In the first part al-Qazwīnī describes the moon, sun, planets, stars, as well as the inhabitants of heaven, angels. At the end of this segment he provides an explanation and chronology of the Arabic and Syrian calendars. The second part starts with an essay on the four Aristotelian elements, meteors and the winds. The author then classifies the earth into seven climates with descriptions of all of the known seas and rivers. He explains the causes of earthquakes and the formation of mountains and wells. Al-Qazwīnī then reviews the three realms of nature: mineral, vegetable and animal. However, the account of the animals is preceded by a description of man, including his character, anatomy and characteristics of his tribes. The section dealing with minerals was translated into German with a commentary by the renowned orientalist Julius Ruska in

*the Best of Stones Ahmad ibn Yusuf Al Tifaschi, Ahmad ibn Tifashi*. [Translator:] Samar Najm Abul-Huda. New York, Rowman & Littlefield Publishers, Inc., 1997. 320 p. ISBN: 0810832941. **References:** Ruska, *Steinbuch des Aristoteles*, 1912, p. 23-31. • Steinschneider, *Arabische Lapidarien*, 1895, p. 254-6. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 125-6. • Wiedemann, *Mineralogie in Islam*, 1912, p. 206-7.

[143] DSB, **13**, ??. • Wiedemann, E., "Über die Entstehung der Farben nach Nasīr al-dīn al-Tūsī," *Jahrbuch der Photographie und Reproduktionstechnik*, **1908** (Halle), p. 86-89. • Wiedemann, E., "Zum Leben von Nasīr al Dīn al Tūsī," *Sitzungsberichte der Physikalisch-medizinischen Sozietät in Erlangen*, **58/59** (1926-7), 58-59 and 363-79. [Published as: *Beiträge zur Geschichte der Naturwissenschaften*, **75**.] • Wiedemann, E., "Nasīr al Dīn al Tūsī," *Sitzungsberichte der Physikalisch-medizinischen Sozietät in Erlangen*, **60** (1928), 289-316.

[144] Ullmann, *Naturwissenschaften im Islam*, 1972, p. 127.

[145] Brockelmann, *Arabischen Literatur*, 1943, **1**, p. 405 & Suppl. **1** , p. 924. • DSB, **11**, ??. • *Encyclopedia of Islam*, **4**, 865-7. • Ruska, J., "Kazwīnīstudien," *Islam. Zeitschrift für Geschichte und Kultur des islamischen Orients*, **4** (1913), 14-66, 236-62. • Sarton, *Introduction*, 1928-52, **2**, p. 868-870.

[146] **Modern edition:** Ferdinand Wüstenfeld., *Zakarija Ben Muhammed Ben Mahmud) el-Cazwini's [al-Qazwini] Kosmographie*. Göttingen, Dieterich, 1848-1849. 2 parts. (I: Die Wunder der Schöpfung. Aus den Handschriften der Bibliotheken zu Berlin, Gotha, Dresden und Hamburg. XII (German text), 452 (Arabic text) p. II: Die Denkmäler der Länder. Aus den Handschriften des Dr. Lee und den Bibliotheken zu Berlin, Gotha und Leyden. X (German text), 418 (Arabic text) p.) [Reprinted, Wiesbaden, Martin Sändig, 1967.] **References:** Steinschneider, *Arabische Lapidarien*, 1895, p. 256-257. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 127-8.

1895.[147]

Al-Qazwīnī's second work, commonly refered to as the *Geography* is known through several manuscripts in two distinct recensions. The first is dated 1262/3 and carries the title, *ʿAdjāʾib al-buldān* (Prodigies of the Countries). The second, apparently a revised version, carries the date 1275/6 and has the title, *Āthār al-bilād wa-akhbār alʿibād* (Monuments of the Countries and History of their Inhabitants).[148] Both versions contain descriptions of the seven climates of the earth. For each clime the separate cities, countries, mountains, islands, lakes, rivers, etc., are listed in alphabetical order. In other words, instead of being one alphabetical dictionary, it is a collection of seven dictionaries, one for each climate. The description of each city and country contains geographical and historical facts along with biographical information on famous personalities originating from them.

### 3.1.20 al-Qibjāqī

Bailak ibn Muḥammad al-Qibjāqī (or al-Qabajaqī) dedicated to the prince of Ḥamāt al-Malik al-Manṣūr II, the son of the Malik al-Muẓaffar II, a work with the title of *Kanz at-tijār fī maʿrifat al-aḥjār* (A Treasure for Merchants regarding the Knowledge of Stones) written in 1282.[149] The writing comprises 30 chapters and followed closely the book of al-Tīfāšī. In the prologue al-Qibjāqī lists 23 authors that he has cited including Aristotle, Theophrastus, Ptolemy, and al-Bīrūnī. The magnetic compass is also mentioned.

### 3.1.21 As-Suwaidī

ʿIzz ad-Dīn Ibrāhīm ibn Muḥammad as-Suwaidī (*died* 1292) wrote the *Kitab Ḥawāṣṣ al-aḥjār mina l-yawāqīt wa-l-jawāhir*.[150] In this small writing 26 stones are treated, with their descriptions derived from other Islamic sources with no originality. Stress is placed on the pharmaceutical uses of the stones that are listed.

### 3.1.22 al-Qāšānī

In 1301 in Tabriz, Persia Abū l-Qāsim ʿAbd Allāh ibn ʿAlī ibn Muḥammad ibn abī Ṭāhir al-Qāšānī wrote the *Kitab ʿArāʾis al-jawāhir wa-nafāʾis al-aṭāyib*.[151] The book treats precious stones giving descriptions of their physical properties, with the final section telling the use of stones in technology.

### 3.1.23 al-Dimašqī

Shams al-dīn Abū ʿAbdallāh Muḥammad ibn abī Ṭālib al-Anṣārī al-Ṣūfī al-Dimašqī (1256-1327)[152] devoted the second chapter of his large *Nukhbat al-dahr fī ʿadjāʾib al-barr wa ʿl-baḥr* (Selection of the Age on the Wonders of the Land and Sea) to minerals, metals and stones.[153] This cosmography, written in the 14th century is the author's best known work and is a compilation dealing with geography in the widest sense that contains a large amount of information to be found no where else. The section on mineralogy is divided into 11 sections. Seven metals are treated in the first, with their physical properties described, their origin in terms of Aristotlian doctrine explained, their active and passive virtues listed, and their relationship with the planets discussed. Physical and magical properties are indiscriminately mixed together. The second portion treats the origin of metals based on their content of sulfur and mercury. Section three refutes alchemy, while part four describes precious stones in which approximately 20 items are

[147] Julius Ruska., *Das Steinbuch aus der Kosmographie*. Übersetzt und mit Anmerkungen Versehen von Julius Ruska. Kirchhain, N.-L., Druck von M. Schmersow, c1895. 44 p. [Published as: *Beilage zum Jahrsbericht 1895/6 der prov. Oberrealschule, Heidelberg*.]

[148] **ADD REFERENCE HERE**

[149] Brockelmann, *Arabischen Literatur*, 1943, **1**, p. 652 & Suppl. **1** , p. 904. • Sarton, *Introduction*, 1928-52, **2**, p. 1072. • Steinschneider, *Arabische Lapidarien*, 1895, p. 256. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 128.

[150] Steinschneider, *Arabische Lapidarien*, 1895, p. 257-258. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 129.

[151] Ullmann, *Naturwissenschaften im Islam*, 1972, p. 129.

[152] DSB, **??**, ??. • *Encyclopedia of Islam*, **2**, p. 291. • Sarton, *Introduction*, 1928-52, **3**, p. 800-802.

[153] **Translation:** Mehren, A.F., *Manuel de la Cosmographie du Moyen Age*. Traduit de l'arabe "Nokhbet ed-Dahr fi 'Adjaib-il-Birr wal-Bah'r" de Shems ed-Dîn Abou-'Abdallah Moh'ammad de Damas, et accompagné d'éclaircissements. Copenhagen, 1874. 468 p. [Reprinted, 1994 by *Islamic Geography* no. 204.; ISBN 3-8298-1192-6.] **References:** Brockelmann, *Arabischen Literatur*, 1898, **2**, p. 130 & 138. • Steinschneider, *Arabische Lapidarien*, 1895, p. 259. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 130.

listed and characterized. Section five treats the less valuable stones like turquoise, carnelian, chrysolith, onyx, jasper, etc. The magnet in its various forms is described in the sixth part. This part has been based almost completely on the *Lapidary of Aristotele*. Part seven describes beads of various types, while section eight treats the remaining minerals like arsenic, salts, borax, etc. In the ninth section other less valuable stones are treated and include malachite, obsidian, marcasite, etc. The tenth portion concerns geological questions, and the final part contains stories about imitation jewels and how one detects them.

### 3.1.24 Ibn Abī Bakr Mustaufī al-Qazwīnī

The Persian historian and encyclopedist Ḥamdallāh ibn Abī Bakr Mustaufī al-Qazwīnī (*died* after 1340)[154] wrote in Persian his *Nuzhat al-qulūb* (Delight of the Heart) in an easily comprehensible style. It is essentially a cosmographical and geographical encyclopedia in which the first part describes the three realms of nature including minerals and stones.[155] From Zakarīyā ibn Muḥammad al-Qazwīnī he copies the organization of the minerals into metals, stones and viscous materials and also the origins of these minerals. Later in the work, the geographical portion of the book discusses in detail the places to find the seven metals as well as the methods of extraction from the earth. He also does the same for the precious stones and for the viscous substances like petroleum, naptha, bitumen, pitch, sulfur, mercury, etc.

### 3.1.25 al-Jildakī

In the second part of the *Al-ikhtisās wa-Durrat al-ġawwāṣ fī asrār al-ġawwāṣ* (Natural and Occult Properties of Animals and Stones),[156] the Muslim alchemist ᶜIzz ad-Dīn Aidamir ibn ᶜAlī ibn Aidamir al-Jildakī (*died* 1342/3)[157] dedicates a long section to stones and minerals. He begins with a discussion of the theory of Aristotles that stones are a mixture of the four primal elements that have been consolidated by fire. Then in five sections the minerals are systematically treated. Section one contains 29 different types of jewels together with many subspecies. Part two treats the relative value and prices of these stones. The third part describes the common minerals, 19 in all. Section four treats 17 varieties that are thought to possess miraculous properties. The fifth portion is dedicated to the stones that are found in animals as well as magnets, altogether 11 pieces are mentioned. Many times, al-Jildakī provides synomyms and linguistic explanations for the names of the stones mentioned, but even so the nomenclature is so disfigured it is difficult to easily determine the actual species described.

### 3.1.26 al-Akfānī

The physician Šams ad-Dīn Muḥammad ibn Ibrāhīm al-Anṣārī as-Saḫāwī al-Akfānī[158] wrote a handbuch under the title *Nuḫab aḏḏaḫāᶜir fī aḥwāl al-jawāhir* (Selection of Treasures concerning the Conditions of Jewels).[159] It is a short work written in the 13th century in which fourteen of the most important precious stones are treated. Here their properties are listed, their localities noted, their values estimated, and their magical and theraputic properties enumerated. Al-Akfānī has relied upon the previous works of al-Kindī, al-Bīrūnī, and the *Lapidary of Aristotle*. A German translation was published by Wiedemann in 1912.[160]

### 3.1.27 al-Majrīṭī

A stone book is attributed to the mathematician and alchemist Abū al-Qāsim Maslama

[154] *Encyclopedia of Islam*, **3**, p. 122. • Sarton, *Introduction*, 1928-52, **3**, p. 630-632.

[155] al-Qazwīnī, *The geographical part of his Nuzhat-al-Qulūb composed in 740 (1340)*. Leyden, Brill, 1915. 2 vols. [Vol 1 text edited by Guy le Strange.; Vol 2 English translation with notes by Guy le Strange.; published as: *Gibb Memorial Series*, **23**, nrs. 1 and 2.] • Stephenson, J., "The zoological section of the 'Nuzhatu-l-qulūb' ( a Persian compendium of science, 1340 A.D.)," *Isis*, **11** (1928), 285-315. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 131.

[156] Brockelmann, *Arabischen Literatur*, 1943, **2**, p. 173-174. • Steinschneider, *Arabische Lapidarien*, 1895, p. 261. • Ullmann, *Natuwissenschaften im Islam*, 1972, p. 131-2.

[157] Holmyard, E.J. "Aidamir al-Jildakī," *Iraq*, **4** (1937), 47-53, biblio.

[158] Sarton, *Introduction*, 1928-52, **3**, p. 899-901.

[159] Ullmann, *Naturwissenschaften im Islam*, 1972, p. 132-3. • Wiedemann, *Mineralogie in Islam*, 1912, p. 207.

[160] Wiedemann, *Mineralogie in Islam*, 1912, p. 211-229.

al-Majrīṭī (*died* c1006)[161] that contains citations from al-Jildakī.[162] The text, known in about ten manuscripts, concentrates on the magical and marvelous properties of precious stones, as well as giving information copied from al-Bīrūnī on the specific gravity of the varieties.

### 3.1.28 Manṣūr

Muḥammed ibn Manṣūr wrote a work in Persian *Gawāhīr Nāmeh* that deals with the important precious stones.[163] Included is a discussion of the specific gravity of the individual gems that has been repeated from al-Bīrūnī.

### 3.1.29 al-Jazarīī

Contained in the encyclopedia of natural science *Tuḥfat al-ᶜjāʾib* compiled by Ibn al-Atīr al-Jazarīī is a section on stones.[164] He writes of the miraculous properties of stones as well as their healing power. He describes talismans, gold, silver, the natural magnet, and minerals derived from the bodies of plants and animals. The seven metals are described as are the precious and semiprecious stones, vitriol, various salts, mercury, sulfur, petroleum, and pitch.

### 3.1.30 al-Ġaffārī

A stone book written in Turkish that appeared under the title *Kitab Yāqūtat al-maḫāzin fī Jawāhir al-maᶜādin* comes from Yaḥyā ibn Muḥammad al-Ġaffārī.[165] Al-Ġaffārī relies particularly on earlier Persian books. He treats minerals and stones in four parts: (1) subterranean substances that are needed for the formation of metals, (2) the jewels, (3) the metals and their alloys, and (4) perfumes.

### 3.1.31 al-Maqrīzī

Abū al-ᶜAbbās Aḥmad ibn ᶜlī Taqī al-Dīn al-Maqrīzī (c1364-1442) authored in 1442 a small work on stones under the title, *Kitab al-Maqāṣid as-sanīya li-maᶜrifat al-ajsām al-maᶜdinīya* (Increasing the Knowledge of Mineral Bodies).[166]

### 3.1.32 al-Wardī

The chapter on stones in the *Ḫarīda* of ᶜUmar ibn al-Wardī begins by discussing colored magical stones.[167] Their supposed occult properties are described and the author mentions especially antimony, vitriol, salt. Altogether 41 stones are treated following Aristotelian principles.

### 3.1.33 Šīrāzī

Muḥammad ibn Manṣūr Šīrāzī authored in Persian for the Sultan Abū l-Fatḥ Ḫalīl Bahādur Ḫān (*reigned*, 1478-1479) the work, *Risāla-i Jawāhir* (Epistles on Jewels).[168] It depends heavily on the work of al-Tīfāšī in its description of about 40 stones. External properties are primarily used to distinguish species and medical uses are noted. The specific gravities mentioned date back to al-Bīrūnī. Ornamental uses as well as technological applications are also cited.

### 3.1.34 al-Baihaqī

ᶜAṭāʾ ibn al-Ḥusain ibn ᶜAlī al-Baihaqī wrote for the Yemen ruler Ṣalāḥ ad-Dīn ᶜĀmir ibn ᶜAbd al-Wahhāb (1488-1517) the *Kitab Maᶜdin an-nawādir fī maᶜrifat al-Jawāhir* (The Mine of the Precious Reference to the Knowledge of Jewels).[169]

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[161] Brockelmann, *Arabischen Literatur*, 1943, **1**, p. 281-282 & Suppl. **1** , p. 431-432. • DSB, **9**, ??.

[162] Dunlop, *Arabic Science in the West*, 1958, p. 78. • Steinschneider, *Arabische Lapidarien*, 1895, p. 251. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 122-3.

[163] Wiedemann, *Mineralogie in Islam*, 1912, p. 208.

[164] Ullmann, *Naturwissenschaften im Islam*, 1972, p. 133.

[165] Ullmann, *Naturwissenschaften im Islam*, 1972, p. 134.

[166] Brockelmann, *Arabischen Literatur*, 1943, Suppl. **2** , p. 37, nr. K. • Lippmann, E.O. von, "Alchemistisches aus Makrizi's 'Beschreibung Aegyptens'," *Chemiker Zeitung*, **54** (1930), 2. • Steinschneider, *Arabische Lapidarien*, 1895, p. 261. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 135. • Wiedemann, E., "Zur Geschichte des Kompasses und zu dem Inhalt eines Gefässes in verschieden Abständen vom Erdmittelpunkt," *Zeitschrift für Physik*, **24** (1924), 166-268. [Includes a description by al-Maqrizi of a magnetic fish for determining directions at sea.]

[167] Ullmann, *Naturwissenschaften im Islam*, 1972, p. 135-136.

[168] Ruska, *Steinbuch*, 1912, p. 31-33. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 136. • Wiedemann, *Mineralogie in Islam*, 1912, p. 208.

[169] Brockelmann, *Arabischen Literatur*, 1943, **2**, p. 213 & Suppl. **2** , p. 253. • Ritter, *Orientalische Steinbücher*, 1935, p. 9-10. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 136-137.

### 3.1.35 al-Mubārak Qazwīnī

Muḥammad ibn al-Mubārak Qazwīnī wrote in Persian for the Ottoman Sultan Selīm I (1512-1520) the *Risāla dar Maᶜrifat-i Jawāhir* (Epistles on Metals and Jewels).[170] It contains an introduction and two parts. The first section in 21 sections treats stones and the second in 8 parts handles the metals.

### 3.1.36 al-Maghribī

Imām Aḥmad ibn ᶜIwaḍ ibn Muḥammad al-Maghribī authored a lapidary before the 17th century *Kitāb Qaṭf al-azhār fī ḥawāṣṣ al-maᶜādin wa-l-aḥjār* (Book of the Properties and Characteristics of Minerals and Stones). The book is derived from other Arabic works on the properties of minerals. The author relies heavily on the *Cosmography* of Qazwīwī, the *Durra* of al-Jildakī and the *Taḏkira* of Dāwūd al-Anṭākī from which he gives quotations.[171] This was the last of the major stone books published by the Islamic authors.

## 3.2 Lithotherapy[172]

The use of stones and minerals in medical therapeutics has existed since the earliest times. Their use has, however, been largely overshadowed in the literature by the studies of remedies based on plants and to a lesser extent animals. Nevertheless, the term 'Lithotherapy' was introduced in the sixteenth century to define the use and preparation of mineral substances in the medical welfare of patients.

In antiquity great belief was placed in the use of gemstones and other mineral substances as cures and remedies for a wide variety of ailments. The treatment involved wearing the stones as amulets, talismans, or rings or in other instances pulverizing the stone for mixture with other ingredients to form noxious prescriptions. Dissemination of this knowledge through the Medieval herbals, pharmacopoeias and encyclopedias, as well as the very popular type of book called a lapidary, clearly gave authority for physicians to prescribe treatments using substances that would today clearly be classed as mineralogical. Such use of stones in medicine, therefore, truly began to flourish in the Middle Ages. In addition, many times these prescriptions were formulated by applying the astrological sign and the mystical powers attached to the stone. For example, diamond because of its unusual strength was thought to ward of the effects of ingested poisons, or wine drunk with dissolved pearls a cure for intestinal distress. Later as alchemy began to develop a universal remedy or catalyst generally called the 'Philosopher's Stone' that could work miracles for patients as well as transmute lead to gold was theorized to exist. It was not until the full development of modern medical science, however, that the vital role minerals play in health was shown. This culminates today in the interesting fact that virtually every pill or tablet prescribed has a mineral component.

### 3.2.1 Lapidaries[173]

[170] Ullmann, *Naturwissenschaften im Islam*, 1972, p. 137.

[171] Brockelmann, *Arabischen Literatur*, 1943, Suppl. **2** , p. 713. • Ullmann, *Naturwissenschaften im Islam*, 1972, p. 137.

[172] A few studies have appeared that provide a history of stones in pharmacy and medicine: H.G. Fühner, *Lithotherapie. Historische Studien über die medizinische Verwendung der Edelsteine*. Erweiterter Abdruck der gleichnamigen Inaugural-Dissertation. Berlin, Verlag von S. Calvary & Co., 1902. [6], 150 p. • Christel Meier, *Gemma spiritalis. Teil I.* München, Wilhelm Fink Verlag, 1977. 542, [2] p., biblio. [See p. 361-459]. • H.H. Otten, "[Piedra de mijada, jade. A medico-historical look at lithotherapy]", *Medische Welt*, **32** (May, 1981), p. 765-766. • U. Räth, *Zur Geschichte der pharmazeutischen Mineralogie*. Braunschweig, Universität Braunschweig, 1971. 273 p. [Published as: *Pharmazeigeschichtlicher Seminar der Technischen Universität Braunschweig*, vol. 12. Covers the history of pharmaceutical mineralogy.] • John M. Riddle, "Lithotherapy in the Middle Ages. Lapidaries considered as medical texts," *Pharmacy in History*, **12** (1970), p. 39-50.

[173] Previous studies of lapidaries, published texts, and stone lore in general include: Alios Closs., "Die Steinbücher in kulturhistorischer Überschau," *Mitteilungsblatt - Abteilung für Mineralogie am Landesmuseum Joanneum, Graz*, **8** (1958), p. 1-34. [Overview of lapidary tradition in Europe, Islam and the Orient.] • Pierre Duhem., *Études sur Leonard de Vince*. Paris, 1906-13. • Joan Evans., *Magical jewels of the Middle Ages and the Renaissance*. Oxford, 1922. 264 p. • *ibid.* and Mary S. Serjeantson., *English Mediaeval Lapidaries*. London, 1933. [Published as: *English Text Society*, no. 190.] • Robert M. Garrett., *Precious Stones in Old English Literature*. Leipzig, 1909. [Published as: *Manchener Beitrage zur romanischen and englischen Philologie*.] • Hendrick Harpestraeng., *Gamle danske urtebøger, stenbøger og køgebøger*. Kopenhagen, 1908-21. [Contains a history of lapidaries.] • Urban T. Holmes., "Mediaeval gemstones," *Speculum*, **9** (1934), p. 195-204. • C.W. King., *Antique gems: Their origin, uses, and value*. London, 1860. • George F. Kunz., *The curious lore of precious stones*. Philadelphia and

Citations to gemstones used as ornaments, talismans, or amulets, and to other minerals and stones used in medicine date back to at least the writings of ancient Egypt and the Near East. But the *lapidary*, a work that described the healing properties of 'stones' may be said to have been invented by the ancient Greeks. These treatises, usually quite short, deal exclusively with metals, stones, and gems, with their medicinal and magical characters particularly mentioned because at the time of their appearance, stones were generally believed to possess these properties and were therefore looked upon with great interest by the public. Physical properties and the composition of the stones were generally not mentioned.

That the lapidaries were very popular not only among the educated classes of the community but also among the middle classes, is shown by the fact that there were many of them and they were in great demand. They were frequently written or translated into the vernacular languages of many of the European countries insuring their wide availability. The goldsmiths and jewelers probably offered them for sale together with their normal merchandise as an aid to set forth the value of their wares, and the customers bought the gems they wore not only for purposes of adornment but for the magical powers which they were supposed to possess. How many of these lapidaries have survived is unknown. Some of them were never printed but are known to exist in the form of manuscripts only, in one or other of the great libraries of Europe. Furthermore, during the Middle Ages, the encyclopediaists incorporated sections of these traditional lapidaries into their own work, sometimes with attribution, but usually not, thus making the material even more widely available.

London, 1913. • Fernand de Mély., *Histoire des sciences les lapidaires de l'antiquité et du moyen age*. Ouvrage publié sous les auspices du ministère de l'instruction publique et de l'académie des sciences. Paris, Ernest Leroux, 1896-1902. 3 vols. [An amazing compilation of ancient lapidaries, translations and commentary that was unfortunately never completed.] • Paul Meyer., "Les plus anciens lapidaires frangais," *Romania*, **38** (1909), p. 44-70, 254-552. • Leopold Pannier., *Les Lapidaries Français*. Paris, 1882. • Paul Studer and Joan Evans., *Anglo-Norman Lapidaries*. Paris, 1924.

Written in a seemingly endless variety of formats and arrangements the European lapidaries may be grouped into one of three general types.[174]

1. The *scientific lapidaries* whose material is derived from such classical writers as Theophrastus, Dioscorides, Damigeron, and Galen.
2. The *magical* or *astrological lapidaries*, sometimes also referred to as the *Alexandrian lapidaries*, because best evidence shows they were written in Egyptian Alexandria in the ninth century C.E.
3. The *Christian* or *Christian symbolic lapidaries* that describes the twelve stones named in the Bible as contained in Arron's breast plate in either Exodus or in the Apocalyptic literature.

These categories although useful in grouping lapidaries of similar types, are in no way absolute, because very often some of the descriptions in one lapidary are derived from titles listed in the other groups.

#### 3.2.1.1 Scientific Lapidaries

Some of the best knowledge of medieval mineralogy is preserved in the scientific lapidaries. These are works that carried forward the ancient traditions of mystical and occult properties of precious stones, by repeating the ideas presented in the ancient works of Theophrastus, Pliny, and the like.

##### 3.2.1.1.1 Marbode (1035-1123)

Marbode,[175] Bishop of Rennes, composed the *Liber Lapidum seu de Gemmis* (Book of

[174] This classification was developed by Joan Evans (*Magical Jewels*, 1922, p. 38) and George Sarton (*Introduction to the History of Science*, 1927, **1**, p. 764). Recently, Halleux has made a further division, splitting the ????? into two, ????? and ????. For this study, the three divisions are sufficient to present the material.

[175] Marbode (Born: Angers, France, 1035; Died: Angers, France, 11 September 1123), whose true name was 'de Marboeuf,' received his early education at Angers. After teaching some time at the cathedral school of Angers, he was put at the head of the educational system of the city and Diocese of Anvers in 1067. Later he became archdeacon and in 1096 Urban II appointed him Bishop of Rennes. In his youth he indulged in many excesses, but from the time he became bishop his life was without reproach. In 1104 he was present at the Council of Tours, and in 1109 he was made administrator of the Diocese of Angers. At the age of eighty-eight he resigned his diocese and withdrew to the Benedictine monastery of St. Aubin at Angers where he died soon after.

Stones or Gems) between 1061 and 1081. It is by far the most important of the early medieval lapidaries, being the first book of its type written in Europe since the Classical Age, and it is the one most widely quoted by the authors that followed. Written between the years 1061 and 1081, the text was composed in 734 Latin hexameters that records the medical and magical properties of some sixty stones. The choice of writing the book in verse was made so that those who referenced it might better remember the content given in the book.[176]

It is a scientific lapidary, having derived much of its information from the second century C.E. Hellenistic lapidary, *De Virtutibus Lapidum*, attributed to Damigeron. Marbode begins his poem with the lines: "Evax, King of the Arabs is said to have written to Nero, Who after Augustus ruled next in the city, How many species of stones, what name and what colors, from what regions they came and how great the power of each one." This reference to Evax King of the Arabs is nearly a direct quote from Damigeron's Hellenistic lapidary. It is also the same Evax referred to by Pliny in the twenty-fifth book of his Natural History in the following words, "Evax a King of the Arabians, wrote a book as touching the virtues and operations of Simples, which he sent unto the Emperor Nero." Nothing further, however, is known the Evax so frequently mentioned in the medieval lapidaries, and he may in fact be a literary invention. In fact when Marbode's authorship is omitted from the early manuscripts the lapidary was usually referred to as the 'Lapidary of Evax'. For other sources, Marbode rarely if ever uses Pliny directly, but took some of his descriptions from Solinus and from Isidore, who are derivative of that famous Roman author.

Marbode then gives his description of some sixty stones that in the early manuscripts are listed without any internal order; it was not until the later printed editions that the verses are arranged alphabetically according to the stone's name. Considering the author's religious life, it is interesting to note that the tone of the poem is distinctly pagan with little concern for Christian symbolism. Marbode's purpose in writing was, as he explains in his Prologue, to reveal the secrets concerning stones. There was a danger, he feared, that revealing the secret powers of the stones to the public would diminish their effectiveness, but he nevertheless believed that the secrets needed to be shared with his readers. He concerns himself with describing the stones, giving their locations and powers, and mentions how they are best used in medicine. Constantly the reader is reminded that the power of the stones are there to be exploited by men who know the secrets he is revealing. This believe was not original to Marbode, and in fact came from ancient sources, but the emphasis he placed on the mystical and practical virtues of each stone starts a line of thought that is followed by virtually all other late medieval lapidarists.

Marbode created a unique book that was the most widely read lapidary of the Middle Ages. As Riddle comments:

> There is a new spirit in his work, not seen in earlier lapidaries, which emphasizes that the knowledge of stones is useful and a means of power for men. Marbode's lapidary then becomes the model for numerous subsequent treatises. More important, the utility of the stone-lore, however magical some of it may seem to moderns, was a constant theme. This trend toward practicality makes a study of De Lapidibus a revealing insight into the formulation period of the 'Renaissance of the Twelfth Century'.[177]

More than 140 manuscripts of this lapidary are known, and before the advent of printing it

[176] Adams, *Birth and Development of the Geological Sciences*, 1938, p. 144, 149-155. • C. W. King., *Antique Gems*, 1860, p. 391-417. [Contains an English translation of Marbode.] • Pannier, *Les Lapidaires Français*, 1882, p. 1-81. • John M. Riddle., "Lithotherapy in the Middle Ages. Lapidaries considered as medical texts," *Pharmacy in History*, **12** (1970), 39-50. [Briefly describes the importance of lapidaries in early medical history.] • *ibid.*, *Marbode of Rennes' De lapidibus considered as a medical treatise with text.* Commentary, and C.W. King's translation, together with text and translation of Marbode's minor works on stones by John M. Riddle. Wiesbaden, Steiner, 1977. xii, 144 p. • Sarton, *Introduction to the History of Science*, 1927, **1**, p. 764-5. • Paul Studer and Joan Evans., *Anglo-Norman Lapidaries.* Paris, 1924. 424 p. [Scientific edition, with abundant notes and glossary, of a number of Anglo-Norman lapidaries, in prose and verse, all derived from Marbode.] • Thorndike, *History of Magic*, 1923, **1**, p. 749-??.

[177] John M. Riddle., *Marbode of Rennes' De lapidibus considered as a medical treatise with text*, 1977, p. ix.

was translated into French, Provençal, Danish, Hebrew, and Spanish. After the invention of printing, 14 edition's appeared between 1511 and 1740, with still other printings at later dates.[178]

In addition, Marbode also wrote three other short lapidaries, one in verse and two in prose, that are less well known.[179] These were works that dealt exclusively with the twelve Christian stones mentioned in the Bible, and their content is firmly anchored in the symbolism of Christian doctrine. A short ninety-nine line poem was written as a prayer thanking God for the twelve stones mentioned in The Apocalypses of St. John the Apostle (21, 9-21) that are the foundation of God's Heavenly City. Each stone is described briefly, followed by Christian symbolism. Any virtues mentioned are supernatural. Marbode, also used the same twelve stones in the same order as the subject of his Christian Prose Lapidary. Just like the verse version, Christian symbolism prevails, but this time with scriptural references. Finally, the Medical Prose Lapidary emphasizes the medical qualities of the twelve stones, but also includes Christian symbolism in the summary. All three works, Riddle suggests, were probably writing exercises for Marbode as he accumulated information for his more important *Liber Lapidum*.

#### 3.2.1.1.2 Albertus Magnus (1193-1280)

Albertus Magnus[180] set as his life's work to place all of Aristotle's extant writings into a coherent system and to reconcile the Greek philosophies with those of the Christian world. To attain this outcome, he scoured the libraries of every monastery he visited for any writings of the Ancients. In this quest he was rewarded with the discovery of several ancient works thought lost. These he had copied under his own eyes, thus preserving them for the future when they might not otherwise have survived. However, Albert's diligence did not locate any copy of what he thought was Aristotle's Lapidary, and what is now known to be a pseudo–Aristotelian work. He was therefore forced to write his own work dealing with minerals. The result is of remarkable interest as it shows not only what the state of mineralogy was in the 13th century, but what Albert thought the science should be.

The *De Mineralibus* (Book of Minerals)[181] is an reflection of the knowledge of minerals in the 13th century structured in the framework of ancient Greek doctrine. Following basic Aristotelian philosophy and guided only by the few lines devoted to mineral substances in Aristotle's Meteorologica, Albertus draws heavily upon his own observations and less so on other medieval and classical sources to describe minerals. Various duties of his religious Order caused him to take frequent trips throughout the territories of France, Germany and Italy. Along the literally thousands of miles traveled on foot by Albertus, he had many encounters with mines, miners and minerals. These impressions he retained in his memory

[178] *Libellus De Lapidibus Preciosis*, first edition, Vienna, 1511, and other early editions of Rennes, 1524, Freiburg, 1531, Paris, 1531, Freiburg in Breisgau, 1531, Cologne, 1539, etc. *Refs.* Sinkankas, *Gemology Bibliography*, 1993, nos. 4168-4193.

[179] John M. Riddle., *Marbode of Rennes' De lapidibus considered as a medical treatise with text*, 1977, p. 21-22.

[180] Albertus Magnus (Born: Lauingen, Swabia, Germany, 1193; Died: Cologne, Germany, 15 November 1280) was one of the most famous authors of the High Middle Ages. He was born to a wealthy and powerful family, which provided him with a good Classical eduction. He studied liberal arts at Padua, where he came under the influence of Joranus of Saxony [?-1236], Master General of the Dominican Order. Against his family wishes, Albert vowed to a life of poverty and entered the Order, eventually being ordained a priest. Around 1241, he was sent to the University of Paris where he quickly rose to the post of Master of Theology. His devotion and knowledge soon lead to his appointment to establish in Cologne a studium generale. This education center was to occupy and consume Albertus for the remainder of his life; among his illustrious students were Thomas Aquinas [1227-1274], Thomas of Cantimpré [1201-after 1280] and Ulrich of Strassburg and Giles [?-1278]. In 1260 the Pope appointed Albertus Bishop of Regensburg, a post he resigned in 1262. The remainder of his long life was devoted to preaching, teaching and writing, primarily at Cologne. He was the most influential medieval educator of the Aristotelian philosphies, and through his position as provost at Cologne, he introduced Greek teachings to the curriculum—a practice soon copied at other education centers. Albertus Magnus was canonized in 1931 by Pope Pius XI, who declared him Saint to all those who cultivate the natural sciences.

[181] Bibliography ...

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until they were later recorded in this work. Consequently, when reading Albertus' words, there is no doubt as to the authority of his citations. One can only regret that the scope of the project was so great as to preclude observations of many phenomena.

The De Mineralibus is divided into five books, dealing with stones (Books I-II), metals (Books III-IV), 'intermediates' (Book V), which are neither stones nor metals, but have characteristics of both. In books, I, III and V the author follows classical philosophy by discussing minerals based upon their causes. This refers to the four causes distinguished by Aristotle as material (the matter from which minerals are made), efficient (the process by which minerals are made), formal (the form which minerals take, assumed by Albertus to be based on biological propagation), and final (the reason the mineral exists). In books, II, IV and V Albertus completes his plan by individually naming stones, metals, and 'intermediates,' and describing each in considerable detail. This type of catalog, alphabetically arranged on the name of the stone was popular in medieval herbals and lapidaries and is a tradition that dates back at least to Pliny. Yet Albertus' De Mineralibus is not a simple lapidary. Even though its background is based in medieval thought, with many errors, the structure of the text is recognizable in modern textbooks (i.e., the introduction of general principles giving the origin, and physical properties of minerals, followed by descriptions of individual minerals including appearance, place of occurrence, uses, etc.). With Albertus Magnus' mineralogy, the study of minerals begins to emerge from its embryonic period into a full fledged science. The tradition of magical and curative powers in gems still permeates the text, but one feels the author fighting the superstitions of the ancient beliefs, and seeing the world in a new, more skeptical and practical view.

#### 3.2.1.1.3 Bartholomaeus de Ripa Romea

Outside of Alfonoso's elaborate lapidary that never enjoyed circulation outside of Spain, apparently one of the most elaborate lapidaries was produced in the mid-thirteenth century by BARTHOLOMAEUS DE RIPA ROMEA. It is a discussion and analysis of 130 stones, gems and minerals arranged in an alphabetical sequence. Known in six unpublished and unstudied manuscripts ranging from the thirteenth through the fifteenth century this work deserves further attention. Authorship is derived from two of the manuscripts that state that they were authored by one Bartholomaeus de Ripa Romea.[182]

#### 3.2.1.1.4 Mandeville

JOHN MANDEVILLE[183] wrote his *Lapidaire*[184] in the French language, which first appeared in manuscripts that date from the middle fourteenth century. Pannier (1882) describes and compares several such manuscripts that had come under his inspection, and concludes that the text was probably not an authentic work of Mandeville, but instead suggests it to be the work of an unnamed jeweler.

The lapidary includes descriptions of the most important precious stones plus many others of a fantastic nature. It begins by copying from MARBODE, the leading lapidary of the period, descriptions of about two dozen stones. Then are given descriptions of other stones and minerals both imaginary and real including pumice, mica, alabaster, and lapis lazuli. Stones formed in the human body or the bodies of animals are very prominent, as these bezoar and eaglestones were believed to bestow on their owner marvelous or supernatural power.

#### 3.2.1.1.5 Camillus Leonardus (1502)

**REWORK:** The Italian physician CAMILLUS LEONARDUS[185] wrote his popular lapidary

[182] John M. Riddle., "Lithotherapy in the Middle Ages. Lapidaries considered as medical texts," *Pharmacy in History*, **12** (1970), p. 39-50. • London, Wellcome Historical Library. MSS 116 and 117.

[183] John Mandeville [c1300-1374] was probably a pseudonym, for the author of the book generally known as *Travels of Sir John Mandeville*, written in Norman French between 1357 and 1371. Virtually nothing is known of Mandeville. Much of the book was borrowed from narratives written by several world travelers and compiled into an entertaining first-person narrative, a compendium of medieval knowledge and speculation concerning such places as Jerusalem, India, and China.

[184] Leopold Pannier., *Les Lapidaries Français*. Paris, 1882, p. ??-??.

[185] Camillus Leonardus was born in Pesaro and

*Speculum Lapidum* (Speculation on Stones) at the beginning of the sixteenth century.[186] It is a work that in many aspects is a transition from the older books about stones and gems to a new scientific understanding that is not mired in the dogma of the past. Dedicating the work to Caesar Borgia, Leonardus divides his subject into three books. The first considers of the origin and nature of stones, with respect to their beauty, color and occult virtue. The second gives an alphabetical list of 279 minerals that are then formally described. Leonardus compiled this list by including every mineral mentioned by previous writers that he was aware off, which gives this book special interest to the historian of mineral studies. However, many of these minerals are now only known by their name alone, the actual mineral having been lost to time. Others are varieties of the same species, while still others are simply fabulous invention. The third book describes the ancient figures to be engraved upon gems and other stones to enhance the virtue of engraved stone, as well as an interesting discussion as to how the stones absorbed the influence of the planets and zodiac constellations and why a stone with any of the twelve zodiac signs is supposed to take on the properties of that sign, as well as listing what those properties are. He mentions that the Israelites in the wilderness were the first who distinguished themselves in this art of engraving gems and that the Romans were the greatest masters of it.

While Leonardus, as he himself states, garnered his material from a succession of older writers, he shows some indications of having come under the influence of the newer methods of study which were about to be advocated by Agricola and his followers, in that he treats of certain physical properties of minerals, such as "Perspicuity and Opacity, Hardness or Softness, Gravity and Lightness, Density and Porosity" and of the importance of these for the recognition of various stones. In fact the *Speculum*, which was one of the most widely read lapidaries of the time, in its successive editions bridged over the transitional period between the old and the new mineralogy. In his lapidary Leonardus follows Albertus Magnus in adopting the Aristotelian theory of the origin of stones through the influences of the heavenly bodies. Gimma, however, states that owing to the inclusion in it of certain ideas and certain statements drawn largely from Arabian sources, the book fell under the condemnation of the Church and was entered in the *Index Expurgtorius*.

#### 3.2.1.1.5.1 Ludovico Dolce (1508-1568)

**REWORK:** In 1565, Ludovico Dolce[187] put his name on the *Libri tre, ne i quali si tratta delle dibersi sorte delle gemme* that upon publication was seen to be nothing more than an Italian translation of Camillus Leonardus' *Speculum Lapidum*. It brought Dolce widespread condemnation as a plagerist because no where in the text does he say Leonardus was his source, let alone even site that other work. There is not the slightest suggestion in Dolce's version as to the original source even though the plagiarism is almost verbatim and the system of numbering chapters, with some unnumbered, directly traceable to that employed by Leonardo Camillus. Adams, for example, in his Birth and Depelopment of the Geological Sciences, p 155, states "the book also figured in one of the most shameless cases of piracy in the whole history of letters, a well-known author Ludovico Dolce, having made a literal translation of it into Italian, which he published at Venice as his own work, without making the slightest reference to the fact that Leonardus was the author of the

flourished in the late 15th and early 16th centuries. He seems to have been a physician and astrologer who worked in Italy. He wrote a number of works, some of which are dedicated to his patron, Cesare Borgia [1475-1507]. *Refs.* Thorndike, *History of Magic*, 19????, **6**, p. 298.

[186] See Sinkankas, *Gemology Bibliography*, 1993, nos. 3891-3896. *Speculum Lapidum*, first edition, Venice, 1502; also, Venice, 1516, Paris 1610, and Hamburg, 1717. An English translation appeared in London, 1750. Other information may be found in Adams, *Birth and Development of the Geological Sciences*, 1938, p. 84, 149, 155-9. • Thorndike, *History of Magic*, 19????, **6**, p. 298-304.

[187] Ludovico Dolce, an Italian poset and translator, was born in Venice to an old but impoverished family. He studied literature and ancient languages, and to support himself wrote many translations. *Refs. Biographie Universal*, **11**, 483-5.

book, in fact on page 3 he refers to it as 'mia fatica'."

In general, the text contains extracts from the works of Aristotle, Pliny, Isidore, Dionysius of Alexandria, Albertus Magnus, and others, and emphasizes the curious rather than the scientific. It treats the natural history of gemstones, their properties which make them desirable for wear, distinctions between true and false gems, the colors displayed by gems, an alphabetical listing of over 200 gemstones, other stones, and some rocks, which have been described by previous authorities, and with brief statements as to their nature and attributes. There is a "book" on engraved gems with strong emphasis placed on the mystical signs and symbols engraved thereon, and which by mere presence were supposed to confer magical powers. Also mentioned here are the famous engravers of antiquity and much curious lore as well as excerpts from the works of Salomon, a famous magician, and Hermes, a noted astrologer. Forgiving Dolce's reprehensible conduct in passing off this work as his own, this and the several versions below served to make the excessively scarce Speculum Lapidum more widely accessible, albeit in disguise. Ferguson, Bibliotheca Cbemica, 2, 27; Thorndike, Hist Magic, 6, 313; Gatterer 2, no 23.

#### 3.2.1.1.6 Martin Steinpreis (c1510)

MARTIN STAINPIES[188] wrote the *Lapidarium Omni Voluptate Refertum*, an interesting and rare lapidary that although undated, is thought to have been printed in Vienna after the year 1500, probably around 1510. The text is divided into two parts. The first containing the introductory material is composed of 13 chapters. At the outset the author states that the purpose of this work is "first to give such information concerning the various minerals as will enable them to be recognized, and second to set forth their origin, virtues and properties" (Adams, 1938). A general description of the particular virtues and properties is explained in the first part of the book. Included are chapters on how the properties manifest themselves, how a weak virtue may be strengthened and the differences between the mystical powers of natural and artificial stones. Throughout, the author denounces those who believe gems do not possess heavenly powers as ignorant fools. He supports this argument by reminding the reader that great authorities such as Aristotle and Plato recognized these qualities as inherent to a stones existence.

The second part of the text is a descriptive list of 117 stones in alphabetical order. Under each name there is a commentary about the individual properties and virtues attributed to the stone. This commentary is largely based upon the writings of Albertus Magnus, Pliny, Evax, Avicenna and Serapion. In fact, many of the notes are copied directly from Albertus Magnus, although some stories of anecdotal nature are also interspersed.

#### 3.2.1.1.7 Erasmus Stella (1517)

ERASMUS STELLA[189] wrote *Interpraetamenti Gemmarum Libellus* that was first published in Erfurt in 1517 and is one of the earliest sixteenth century treatises on mineralogy and precious stones.[190] It is a different type of lapidary than those that came before, with its arrangement of gems and minerals according to color rather than the typical alphabetical sequence. The four color classes Stella developed are white, green, red and blue or black. Thus are classified:

I. De gemmis candidis, including diamond, rock crystal, iris, ceraunia & astroite, pederote, asteria, achate, draconite, allectorio, and margaritis.

[188] Martin Stainpies (Born: late 1450s; Died: Vienna, Austria, 14 July 1527) matriculated at the University of Vienna in April, 1476, gaining his medical degree in 1488 and his license to practice medicine on 23 September 1490. He became professor of medicine at the Vienna Medical School, and between 1496 and 1510 he was eight times elected Dean of the medical faculty. By 1510 he was one of the senior doctors at the medical school. In the plague year of 1511, Stainpeis criticized colleagues who fled the city, and was called before a committee investigating this slander. After his refusal to appear, Stainpeis' faculty privileges were revoked. He wrote several medical tracts, the last of which is considered the first printed introduction to the study of medicine.

[189] Erasmus Stella (Born: c1450; Died: Zwickau, Germany, 1521) was a German physician who studied medicine at the Universities of Leipzig and Bologna, from where he received his M.D. He was appointed town physician of Zwickau in 1501, later becoming Burgomeister.

[190] Sinkankas, *Gemology Bibliography*, 1993, nos. 6331-6333.

II. De gemmis viridibus, including smaragdo (emerald), beryllis, chrysoprasio, topatio, callaide, prasio, heliotropio, jaspide.

III. De gemmis rubeis, including carbunculorum generibus, amthysto, hyacintho, sarda, sardonyce, anyce, hematite, corallio, hephesite, chrysolito, electro, and opalo.

IV. Gemmis coeruleis & nigris, including cyaneo, saphiro, calaide & ceraunia, de moris gemmis, de gemmis ad ectypam, etc.

In this manner thirty-three gems and minerals are arranged, with some items receiving extended description while others are mentioned by name alone. The longer commentaries give a fuller picture than many previous lapidaries with little or no value attributed to magical or supernatural virtues. The most important facet of this work is, however, that it attempts in some manner to systematically arrange the minerals, which is perhaps the first explicit attempt at a mineral classification since the invention of printing. Adams (1938) notes that the descriptions are better than earlier works, although Thorndike (1923-58) declares the work "little more than a compilation from Greek and Latin writers, above all, Pliny."[191]

#### 3.2.1.2 Alexandrian Lapidaries[192]

In the early years of the Christian era in the Egyptian city of Alexandria an important intellectual center formed. All manner of subjects were studied at the city's great library and a full curriculum of learning was available at the Serapion, a type of university. In this environment many new books were written including a small group of works dealing with stones sometimes referred to as the Alexandrian lapidaries.

These lapidaries were written in Greek and describe the magical powers and occult virtues attributed to precious and nonprecious stones. These books became very popular. They derived there ideas from an eastern influence of belief in magic which at that time was creeping into western imagination. It was further believed that a stone's power could be enhanced by engraving upon its surface specific symbols or astrological signs. This led to a great demand for the engraved amulets and charms worn by people to fend off evil spirits or disease, or alternately, invite luck and prosperity. The authors are mostly unknown, and the texts make no real contribution to mineralogy, but they do show how minerals and gems were viewed and valued at the time.

##### 3.2.1.2.1 Kyranides[193]

A Greek work dealing with the medical properties of natural objects is the *Kyranides* (Κοιρανιδεσ), also sometimes called the *Koraides*, whose uncertain authorship is sometimes attributed to Hermes Trismegistos. This work probably of the second or third century C.E. has an unmistakable relationship to the Hermetic corpus and the *Physiologos*. It is a composite work containing references to Greek medicine and festivals, Mithraic rites, Babylonian astrology, and Jewish religion, whose undoubted origin was the city of Alexandria, the only commingled society of the time that would nurture such a writing. It treats the magical powers of plants, animals, and gemstone talismans and left traces of its authority throughout the scientific literature of the Middle Ages. For example, the *Kyranides* is one of the sources for the medieval tales of the fabled unicorn.

The division of the text within the *Kyranides* is into four books. The first is on magic, while the other three, which originally formed a separate work, treat respectively, animals, birds, and fish. In each of these books the text is arranged alphabetically into twenty-four chapters, that being the number of characters in the Greek alphabet by which it is organized. Under each letter of the alphabet there is then listed the name of a

[191] Adams, *Birth and Development of the Geological Sciences*, 1938, p. 147-149. • Sinkankas, *Gemology Bibliography*, 1993, nos. 6331-6333. • Thorndike, *History of Magic*, 19????, **6**, p. 302-303.

[192] For further reading: Adams, *Birth and Development of the Geological Sciences*, 1938, p. 28-32. • F. Susemihl., *Geschichte der griechischen litteratur in der Alexandrinerzeit*. Leipzig, 1891. 2 vols. [p. 856-867].

[193] Other information may be found in: Adams, *Birth and Development of the Geological Sciences*, 1938, p. ?? • Baisier, *The Lapidaire Chrétien*, 1936, p. 5. • Closs, *Steinbücher*, 1958, p. 8-9. • Evans, *Magical Jewels*, 1922, p. 18-19. • Mély, *Les Lapidaires Grecs*, 1898, **3**, p. 33. • Partington, *History of Chemistry*, 1971, **1**, pt. 1, ??-??. • Thorndike, *History of Magic*, **2**, p. 229-235.

plant and animal and sometimes a stone whose name begins with that letter. The lapidary portion consists of the description of how each stone is to be engraved in order to enhance its specific virtue or healing power. The influence of two guiding principles, good and bad, is recognized when creating the talismans. A powerful amulet is then created when this engraved stone is placed in a small bag with other ingredients and worn by the patient. In this way the virtues and merits of 52 stones were discussed.[194] Of these 36 originate from the earth while 16 are derived from animals. All the stones are mentioned in the ancient and medieval lapidaries. For example, of the 24 stones that represent the element of fire in the first *Cyranide*, fifteen are found in PLINY's *Natural History* and seventeen are found in the medieval lapidary of LEONARDUS. Adams (1938) gives a full account of the other stones.

#### 3.2.1.2.2 α-Plutarch

**REWORK:** To the Greco-Roman writer Plutarch a work entitled *Treatise on Rivers and Mountains* (Περι ποταμωυ) is sometimes attributed, it being sometimes included in the printed collections of his writings; however, it is now generally accepted that the work is not genuine, and the author is referred to as α-Plutarch. The text probably dates from the first quarter of the third century C.E., and is reminiscent of the *Kyranides* which is also arranged in twenty-four chapters, that number corresponding to number of letters in the Greek alphabet. It is a magical and medical treatise, originally arranged such that each chapter described some plant or stone found in a specific river or at the base of a mountain and to the mythical ideas associated with it.

Woven into the descriptions are a wealth of allegorical ideas, with charms for protecting treasure, capturing tigers, putting demons to flight, keeping dogs from barking, curing leprosy, fevers, hemorrhages, and for a great variety of other more or less useful purposes. The author gives his authorities but it is doubtful that any of the works he mentions existed since they are only referenced in this work. The rivers and mountains are merely mentioned as those where these plants or stones possessing magical powers are to be found or where certain mythological events took place, from which in many cases the river or mountain derives its name. There are twenty-four stones mentioned in his *Treatise on Rivers and Mountains*, some of them, as for example beryl, asterites and sardonyx, being well known; others are well-known stones which here appear under new names, as "cylinder," just mentioned as occurring on Mount Cronius, which is the well known Ceraunia or thunder-stone mentioned by Pliny and found in most of the medieval lapidaries; the Linurge is the Amianthus and the Collote is the Chelidonius. Others bear new names and cannot be identified, if indeed they are not wholly mythical, such as Corybas, Sicyone and Mynda.[195]

#### 3.2.1.2.3 α-Orpheus

ORPHEUS is given as the supposed author of a later Grecian poem titled *Lithica* (Λιθικα)[196] composed in 768 verses that gives the virtues of 27 gems with considerable allusion to their magical properties, but with no mineralogical information concerning them. Only fragments of the original Greek text have survived, the work having passed to the present through a nearly complete, early Latin translation. The authorship is uncertain because the poem is supposed to have appeared soon after the prose treatise written by Damigeron who lived in the second century B.C.E. However, research shows the medicinal and chirurgical powers attributed to the stones in the *Lithica* are derived from many later authors that extend down to Galen who wrote in the second century C.E. The content and the style of the poem also indicates that the author actually lived long after the birth of Christ, but before the Emperor

[194] Leo J. Henkin., "The Carbuncle in the Adder's Head," *Modern Language Notes*, **58** (Jan., 1943), no. 1, p. 34-39.

[195] Adams, *Birth and Development of the Geological Sciences*, 1938, p. 30-31. • Mély, *Les Lapidaires Grecs*, 1898-1902, p. liv.

[196] *Lithica*, first edition, Venice, 1517, other early edtions: Florence, 1517, Paris, 1566, and Liege, 1576. • *Orphei Lithica, accedit Damigeron de lapidibus* (Berlin, 1881) is a modern critical examination of the poem. *Refs.* Sinkankas, *Gemology Bibliography*, 1993, nos. 4886-4899.

Constantine. Based on this evidence the work is now dated to the fourth century C.E., and the actual author is unknown. Among the stones included in the poem are quartz, diamond, jasper, topaz, opal, chrysolite, magnet, coral, agate, hematite, sardius, and emerald.

#### 3.2.1.3 Christian Lapidaries[197]

The Christian lapidary was a persistently popular form, especially during the Middle Ages. Also sometimes called *The Twelve Stones*, these books focused attention on the stones mentioned in the Bible, especially two (different) lists of 'twelve stones' — those in the breastplate of the High Priest (*Exodus*, xxviii, 17-21; xxxix, 10-14) and those in the foundations of the New Jerusalem (*Apocalypse*, xxi, 19-21). These books also reflect pagan practices with respect to the magical properties of stone, which was to legitimized by placing them under the umbrella of a commentary on the Bible.

The ultimate source of the miraculous and symbolical properties of the precious stones is the Bible. There is a description of the stones on the breastplate of the high priest in Exodus xxviii: 17-20, and in the Apocalypse xxi, 19-20 there is a description of the foundations of the New Jerusalem Bede and other lapidary authorities of the Middle Ages discussed only the stones listed in Exodus since the Hebrew names are not clear, the Biblical translations vary among themselves in identifying the stones. The main scientific discussion of precious stones and minerals was in Book 37 of Historia naturalis Pliny the Elder, in which he makes a synthesis of all that had been written before Saint Isidore of Seville used this material in Book 16 of his Etymologiae, in which he arranged the minerals according to color During the Hellenistic period there appeared at Alexandria stone books of a magical and mystic sort, which were written in Greek One of these, the Damigeron was popular in Western Europe, and may have been translated into Latin by the first century.

##### 3.2.1.3.1 Epiphanius

About 400 C.E., Epiphanius,[198] Bishop of Salamis, authored in Greek, *Peri Tou Lithon=On the Twelve Precious Stones* (Περι των ιβλιθωγ) that identified and described the twelve stones contained in the breastplate of Aaron, the High Priest of the Jews. Appearing in the fourth century C.E., this is one of the earliest Christian lapidaries. Apparently, this text was at an early date translated from Greek into Latin as *De Duodecim Gemmis*, because the only early copies known are in that later

[197] Other historical information may be found in: Léon Baisier., *The lapidaire chrétien, its composition, its influence, its sources*. Thesis (Ph.D.). Catholic University of America, 1936. vii, 130 p. [The Catholic University of America. Publications of the Department of Romance Languages and Literatures, 14; reprinted by AMS Press, 1969.] • Edward Clapton., *The precious stones of the Bible—descriptive and symbolical being a treatise on the breast plate of the high priest, and the foundation of the New Jerusalem with a brief history of each tribe and each Apostle*. Second edition. London, Simpkin, Marshall, Hamilton, Kent, 1899. xxxii, 231 p. • Charles William Cooper., *The precious stones of the Bible, with an account of the breastplate of the high priest, the ephod and urim and thummim*. London, H.R. Allenson, limited, 1924. 127, [1] p., frontispiece. [Bibliography, "Authorities quoted," p. 126-127.] • E.L. Gilmore., "Gemstones of the First Biblical Breastplate?," *Lapidary Journal*, **22** (1968), p. 1130-4. • Samuel S. Kottek., "Precious stones in Jewish and Christian medieval literature: natural and/or occult sciences?", *Koroth*, **16** (2002), p. 89-110. • Gisbert Kranz., *Europas christliche Literatur von 500 bis 1500*. Paderborn, F. Schöningh, [1968]. 525 p. [A history and criticism of Christian literature from the year 500 to 1500. Continued by the author's companion volume, *Europas christliche Literatur von 1500 bis heute*.] • *ibid.*, *Europas christliche Literatur von 1500 bis heute*. Zweite Auflage. Paderborn, F. Schöningh, 1968. 655 p. [A history and criticism of Christian literature from the year 1500 to today. Continued by the author's companion volume, *Europas christliche Literatur von 500 bis 1500*.] • R.V. Wright and R.L. Chadbourne. *Gems and minerals of the Bible*. New York, Evanston and London, Harper & Row, Publishers, 1970. xii, 148 p., illus., index. • August Wünsche., *Die Bildersprache des Alten Testaments*. Ein Beitrag zur aesthetischen Würdigung des poetischen Schrifttums im Alten Testament. Leipzig, Eduard Pfeiffer, 1906. v, 187 p. [Includes a discussion of minerals and gems mentioned in the Bible.]

[198] Epiphanius (Born at Besanduk, near Eleutheropolis, in Judea, after 310; died in 403), while very young, chose to follow the monastic life in Egypt. On his return to Judea he founded a monastery at Besanduk and was ordained to the priesthood. In 367 his reputation for asceticism and learning brought about his nomination as Bishop of Constantia (Salamis) the metropolis of the Island of Cyprus. For nearly forty years he fulfilled the duties of the episcopate. He undertook many missions for the church that involved much travel. He died during a return journey to Cyprus. *Refs.* Xxx xxxxxx xx xxxx. Xxx xxxxxx xx xxxx. Xxx xxxxxx xx xxxx. Xxx xxxxxx xx xxxx. Xxx xxxxxx xx xxxx.

language. In 1565, the book was printed for the first time, perhaps being the first appearance of any book on that subject to come off the press. Besides its separate appearance, copies of the book were bound up with several other gem and mineral works as Conrad Gesner's *De Omni Rerum Fossilium* (1565).[199]

Using a common literary device of his age, Epiphanius writes his text in the form of a letter to his friend, Diodorus, Bishop of Tyre. In it, he identifies and describes the twelve stones set in the breast plate (*Exodus*, 28, 17-20) that in order are: sard, topaz, emerald, carbuncle, sapphire, jasper, lyncurius, agate, amethyst, chrysolite, beryl, and onyx. Because of Epiphanius' authority as a high official of the Catholic Church, this work assumed great influence among later biblical scholars. Biblical commentators exercised great ingenuity in attempting to identify the ancient stones, but also in assigning to them allegorical or mystical meanings. Epiphanius was no different. In spite of the absolute Christian theme *De Duodecim Gemmis*, vestiges of the magical virtues attributed to gems survive in his text. For example, the medical properties of agates against snake bite are recounted without further explanation.[200]

### 3.2.1.3.2 Bede[201]

The earliest of Bede's biblical commentaries was the *Explanatio Apocalypsis* (The Explanation of the Apocalypse) probably composed between 703 and 709 C.E.

Commentators of the Bible used great ingenuity in attempting to identify the stones mentioned in the Bible, but also in giving the allegorical or mystical meanings. Bede in his *Commentary of the Apocalypse* represents a good example of this type of literature.

By the Venerable Bede (Written about 710 -16)

This commentary on the Revelation of John, which Bede himself called 'Expositio' instead of the 'Explanatio' of the printed version, is probably the earliest of his scriptural commentaries. According to Laistner, 72 manuscripts are still in existence, with the likelihood of another existing in Melk.

Bede's Commentary did not only enjoy a certain popularity within his own time, but his reputation spread into Europe and his works were still widely used in the twelfth and thirtheeth century. The large number of surviving manuscripts stands witness for this immense popularity.

In a letter to Eusebius, Bede describes the seven sections into which he sees the Book of Revelation divided and explains his own structure into three books.

The translation cited here can be found in Rev. Edward Marshall's book The Explanation of the Apocalypse by Venerable Beda.

### 3.2.1.3.3 Volmar (c1252-1254)

The German poet, VOLMAR[202] authored *Ein wahrhafftig büchlein gar nüczlich zu hören*,[203] which is a short poetic lapidary. It was written sometime between 1252 and 1254 and first printed in Erfurt by Hans Spörer in 1498. It describes 38 gemstones in 1008 verses, and includes the 12 stones of the Apocalypse. Information about the stones is derived from several unnamed sources. Described species include: Almendein, Topasius, Smaragdus, Karfunckel, Jochant, Cristall, Achat, Amantist, Crisoleite, Onichilus, Jaspis, Dyemant, Kappenstein, Carniol, Corall, Antite, Schwalwenstein, Zinen, Aldropi, Kröttenstein, Merayte, Calcosan, Perlein, Mucros, Oytalias, Türckis, Elyte, Calcedon, Sardius, Flammat,

[199] Bibliography ...
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[200] Evans, *Magical Jewels*, 1922, p. 29-30. • Sinkankas, *Gemology Bibliography*, 1993, nos. ??-??.

[201] Possible references include: Peter Kitson., "Lapidary Traditions in Anglo-Saxon England: Part 1, the background," *Anglo-Saxon England*, **7** (1978), 9-60; and *ibid.*, "Lapidary traditions in Anglo-Saxon England: Part II, Bede's 'Explanatio Apocalypsis' and related works," *Anglo-Saxon England*, **12** (1983), 73-123. • Sarton, *Introduction to the History of Science*, 1927, **1**, p. 510-512.

[202] Volmar ...
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Gamachw, Rubein, Balas, Crisoforas, Granat and Jachänt, Diacoda, Barill, Sarderein, Crisopras, Augstein, Ademast, Crisolitus, Topasius, Gagatometus, and Domedus.[204]

### 3.2.1.3.9 Alfonso X (1221-1284)

The Spanish King, Alfonso X (1221-1284), also called "El Sabio," was highly learned and a poet.[205] He set as a goal to have published a series of books that would codify all knowledge. To achieve this, his method was to gather together a group of translators, compilers, and writers, who were then supplied with all the necessary materials in the four languages of Hebrew, Arabic, Latin and Romance, and they set to work. All available material on the subject under study was compared and accounts given in one manuscript were weighed against accounts in others and decisions made with all available knowledge and the advice of experts. Once a manuscript was created a committee would review the text and pass on its content. Unfortunately, Alfonso's survey of knowledge was never realized because his later life was occupied with political intrique and financial difficulties, ending in his defeat at Seville.

One work that was the product of Alfonso's project was the *Lapidary of Alfonso X*, which is a beautifully illuminated lapidary known in a single recorded manuscript that is located in the Escurial Library in Spain.[206] It is said to be a Chaldean lapidary of unknown date, which was translated into Arabic by Abolays and from Arabic into Spanish by Garci-Perez. This latter translation was finished in 1278. The basis of classification is color "Cast into the 12 signs of the Zodiac." The treatment of the virtues and powers of the stones as influenced by the stars and changing according to the position of the planets indicates the complexity of the connection made by Arabic science between minerals and the celestial forces. Evans, who gives an extended review of the work, states that it deals with 360 "stones" among which are included substances such as sulphur, soda and even sponges. Meyerhoff and Foster say that it describes 280 "stones," with brief references to some of their physical properties, uses and medicinal values.

### 3.2.1.4 Byzantine Mineralogy[207]

Byzantine literature is not lacking in lapidaries. These works almost always concentrated on the magical and medical properties of the stones, with little mineralogical content. Astrological properties of stones are sometimes linked with seasonal growth of herbs and other spices, and Byzantine authors strove to make connections with the growth of stones within the earth. Although precious and semiprecious stones are the chief object of study, other 'mined' materials such as coral, magnetite, and amber increasingly drew the attention of later writers, and information regarding the astrological, alchemical, and pharmaceutical uses was collected.[208]

The best known precious stones descriptions occur interspersed throughout the 3,062 verses of Meliteniotes' allegorical poem on Temperance. In the *Sōthrosynm* (Σωθροσυνμ) more than eighty lines are given over to cataloging alphabetically 221 gemstones that were said to decorate the bed of the virgin Temperance in Paradise.[209] Essentially, it is a mineralogical

[204] Adams, *Birth and Development*, 1934, p. 146. • W. Kleist., "Eine neue Handschrift von Volmars Steinbuch," *Zeitschrift für deutsche Altertum*, **103** (1974), p. 185-192.

[205] DSB, **??**, ??. • Sarton, *Introduction to the History of Science*, 1927, **1**, p. 834-842.

[206] Nunemaker, J.H., "Some mediaeval Spanish terms of writing and illumination," *Speculum*, **5** 1930, 420-4. [This study is based on the Lapidary of Alfonso X.] • Nunemaker, J.H., "An additional chapter on magic in mediaeval Spanish literature," *Speculum*, **7** (1932), 556-64. • Nunemaker, J.H., "In pursuit of the sources of Alfonsine lapidaries," *Speculum*, **14** (1939), 483-9.

[207] Other general material may be found in: Karl Krumbacher., *Geschichte der byzantinischen Litteratur*. 2 Auflage. München, 1897. 2 vols. [Reprinted, New York, Burt Franklin, 1958.; History and criticism of Byzantine literature.] • *The Oxford dictionary of Byzantium*. Edited by Alexander P. Kazhdan, et al. New York, Oxford, 1991. 2 vols.

[208] J.C. Edmondson., "Mining in the later Roman Empire and beyond," *Journal of Roman Studies*, **79** (1989), p. 84-102. • J. Riddle., "Amber in ancient pharmacy," *Pharmacy in History*, **15** (1973), p. 3-17. • D. Samsaris., "Les mines et la metallurgie de fer et de cuivre dans la province romaine de Macedoine," *Klio*, **69**(1987), p. 152-62. • S. Vryonis., "The question of the Byzantine mines," *Speculum*, **37** (1962), p. 1-17.

[209] Closs, *Steinbücher in Kulturhistorischer*, 1958, p. 7 • Krumbacher, *Geschichte Byzantinischen Litteratur*, 1897, p.

dictionary written in verse. Under the name Zoroaster survive fragments of lapidaries that are closely related to passages in the Greek magical papyri.[210]

Michael Psellos,[211] of the eleventh century c.e., was a tutor to Emperor Michael Parapinaces and was perhaps the most learned Greek of his time.[212] He authored a small work in Greek on stones, *Peri Lithon* (Περι λιθων).[213] The twenty-four stones it describes in order are diamond, haematite, amethyst, carbuncle, aeschates, beryl, galactites, amber, jasper, idaeus-dactylus, crystal, lychnites, magnet, onyx, caprinus, sardonyx, selenites, emerald, hyacinthus, chrysolithus, chryselectrus, chrysoprasus, chalazias, and topazion.[214]

Psellos' work carries on the Greek hermetic tradition of Dioscorides by describing the medical uses of the stones. All of the gems are either worn as a talismans or crushed and mixed with milk to be taken internally. Strongly influenced by the Eastern philosophy it pays special attention in its descriptions to ophthalmia and other diseases of the eyes, headaches, and fevers.[215]

### 3.2.2 Herbals[216]

In a history of mineralogy, it would seem that the merits of the early herbals would seem limited, but the facts are quite different. As a group, this type of book records the late medieval view of the natural world in terms of how nature could be used to benefit man. Relationships and the uses of plants, animals and minerals discussed in these texts offers insight into the early development of medicine, agriculture and pharmaceutical therapies for

782-786. • Mély, *Les Lapidaires Grecs*, 1898-1902, **2**, p. 205-208. • Terpening, *Lapidary of l'Intelligenza*, 1973, p. 80.

[210] H.D. Betz, ed., *The Greek Magical Papyri in Translation*. Chicago, 1986, vol. 1. • J. Bidez and F. Cumont., *Les mages hellénisés Zoroastre, Ostanès et Hystaspe*. Paris, 1938, **2**, p. 197-206.

[211] Michael Psellos or Psellus (Born: Constantinople, Turkey, 1020; Died: Constantinople, Turkey, c1110) was a Byzantine writer, philosopher, politician, and historian. He was educated in Constantinople. He became an influential political advisor to emperor Constantine IX Monomachos (reigned 1042-1055). During the same time, he became the leading professor at the newly founded academy of Constantinople, bearing the honorary title of 'Consul of the Philosophers'. Towards the end of Monomachos' reign, Psellos found himself under political pressure and retired. However, after Monomachos' death, he was soon recalled to court by his successor. He remained active in politics, serving as a high-ranking political advisor to several successive emperors. Psellos wrote a number of books, probably the best known is the *Chronographia*. It is a history of the Byzantine emperors during the century leading up to Psellos' own time. *Refs.* Internet search. • Sarton, *Introduction to the History of Science*, 1927, **1**, p. 750-751. • Smith, *Dictionary of Greek and Roman Biography and Mythology*, 1849, **3**, p. 562-563.

[212] It was once thought that there were two Byzantine writers of the name, Michael Psellos, both supposedly authors of lapidaries. This belief was based on an biographical entry in a medieval chronicle, but it is now believed that the entry was the mistake of an ignorant copyist.

[213] First Latin edition contained in: *Plutarchi Libellus de fluviorum et montium nominibus ... P.J. Maussacus recensuit, Latine vertit, et notis illustravit ... Pselli de lapidum virtutibus libellus.) P. J. Maussaci appendix ad notas suas in Harpocrationem.* (Tolosæ, 1615, and other editions).

[214] Closs, *Steinbücher in Kulturhistorischer*, 1958, p. 7 • Evans, *Magical Jewels*, 1922, p. 32. • King, *Natural History of Precious Stones*, 1867, p. 13. • Marx, *Geschichte der Crystallkunde*, 1825, p. 10. • Mély, *Les Lapidaires Grecs*, 1898-1902, p. 201-204. • Annibale Mottana., "Storia della mineralogia antica. I. La mineralogia a bisanzio nel XI secolo D.C.: I poteri insiti nelle pietre secondo Michele Psello," *Ren. Fis. Acc. Lincei*, Ser. 9, **16** (2005), 227-295. [A detailed history of Michelle Psello's lapidary of the eleventh century.] • Pierpaolo Galigani., *Il De Lapidum virtutibus di Michele Psello: Introduzione, testo critico, traduzione e commento*. 121 p. [Published as: *Quaderni dellIstituto di filologia classica Giorgio Pasquali dellUniversità degli studi di Firenze*] • M. Psello., *Scripta minora*. Herausgegeben E. Kurtz und F. Drexl. Berlin, 1936-41. 2 vols. • R.H. Terpening., "The lapidary of 'L'Intelligenza'. Its literary background," *Neophilologus: Modern Language Quarterly*, **60** (1976), 75-88. • Steven A. Walton., "Theophrastus on Lyngurium. Medieval and Renaissance Lore from the Classical Lapidary Tradition," *Annals of Science*, **58** (2001), no. 4, p. 357-79. • Wellmann, *Gemmenbücher der Antike*, 1936, p. 97, 102-??.

[215] Mély, *Les Lapidaires Grecs*, 1898-1902, "Les cachets d'Oculistes et les lapidaires de l'antiquité e du haut moyen age," *Revue de Philologie*, **16** (1893), p. 81-??. [Described the role the ancient lapidaries played in treating the diseases of the eye.]

[216] Further historical information may be found in: F.J. Anderson., *An illustrated history of the herbals*. New York, Columbia University Press, 1997. xiv, [2], 270 p., illus. • K. Becher., *A catalogue of early herbals*. Mostly from the well-known library of Dr. Karl Becher, Karlsbad with an Introduction by Dr. A. Klebs. Nyon Bulletin XII. Lugano, L'Art Ancein S.A., 1925. 61 p., illus. [Bookseller catalog describing the extensive collection of early herbals formed by Dr. Becher.] • K.E. Heilmann., *Kräuterbücher in Bild und Geschichte*, Münich, K. Kölbl, 1966. 422 p., illus. [Heavily illustrated history of the early herbals.] • A.C. Klebs., "Herbals of the fifteenth century. Incunubula lists I," *Papers of the Bibliographical Society of America*, **11** (1917), nos. 3-4, p. 75-92 & **12** (1918), nos. 1-2, p. 41-57.

the common person. In short, the herbals retain their relevancy to early mineral studies.

The early printed herbals are among the most remarkable of the stream of books printed in the incunabula period because they are milestones in the history of printing and scientific illustration. Although the name implies a strictly botanical treatise, this class of book refers to a practical medical text intended for both physicians and the common folk. It appeared in reaction against the expensive apothecary, calling attention to a wide range of easily available natural remedies derived from plants, animals and minerals. In fact the last section usually contains a good (for the time) descriptive mineralogy which emphasised the medical use of the described stone. In their time, these volumes were a very popular technical literature, and regularly relied upon by their readers to provide cures for various ailments.

This class of literature may be organized into three broad categories, which were frequently intermixed. Sections and entire chapters were commonly copied into new editions from earlier printings. Priority for the *Herbarius* dates to the 1484 printing made by Schoeffer, which contains 150 illustrated chapters. Schoeffer's composed a second herbal comprising 435 chapters, was published at Mainz in 1485 and was termed generally *Der Gart*. The third and final member of the herbal triad consists of 1,066 chapters and is referred to by the descriptor *Hortus* or *Hortus Santiatas*. In the past, these three distinct families have been confused, with some researchers stating that they are translations of each other, which is not possible. By relying on the number of chapters within the text, 150, 435 and 1,066 respectively, it is possible to determine if a specific herbal is derived from the *Herbarius*, *Der Gart* and *Hortus*.

### 3.2.3 Pharmaceutical Mineralogy[217]

### 3.2.4 Mineral Poisons & Cures[218]

## 3.3 Encyclopedias[219]

Much information concerning medieval mineralogy is derived from the encyclopedias of the period. It was impossible for everyone to attend a university, therefore, some method of distributing general knowledge was necessary. The issue was resolved by compiling encyclopedias that collected together facts, writings, and anecdotal information from a wide swath of sources. These works varied widely in arrangement and completeness, both their focus on education was always present. Encyclopedias were the textbooks and main references for the learned class of scholars and well as the clergy, and were especially important when no library was available. In essence when they were written these works intended to capture a picture of the large palette of all human knowledge.

The writers of encyclopedias compiled their material by scouring other, usually older writers, whose works in some cases have since completely disappeared except for the quotations preserved in the encyclopedias. Thus, a large portion of the information they

[217] Other historical information may be found in: U. Räth., *Zur Geschichte der pharmazeutischen Mineralogie*. Braunschweig, Universität Braunschweig, 1971. 273 p. [Published as: *Pharmazeigeschichtlicher Seminar der Technischen Universität Braunschweig*, vol. 12. Covers the history of pharmaceutical mineralogy.] • Bernard E. Read and Phu Chu-Ping Pak., "A compendium of minerals and stones used in Chinese medicine, from Pên Tshao Kang Mu, Li-Shih-Chen, 1597 A.D.," *Peking, Society of Natural History Bulletin*, **3** (1928), no. 2, vii, 120 p. [Revised and reissued separately, French Bookstore, Peiping, 1936, 2nd edition.] • Wolfgang Rudolph Reinbacher., *Healing earths the third leg of medicine. A history of minerals in medicine with rare illustrations from 300 to 1000 years ago*. [Bloomington, IN, 1st Books Library], 2003. xiv, 244 p., illus. [ISBN 1-403-35096-5]. • John M. Riddle., "Lithotherapy in the Middle Ages. Lapidaries considerded as medical texts," *Pharmacy in History*, **12** (1970), p. 39-50. [Briefly describes the importance of lapidaries in early medical history.]

[218] General histories include: M. Amberger-Lahrmann and D. Schmähl, eds., *Gifte: Geschichte der Toxikologie*. Berlin; New York, Springer-Verlag, c1988. xi, 351 p., illus., portraits. Bibliography includes bibliographical references and indexes. [A general history of poisons.] • Dieter Martinetz., *Poison: sorcery and science, friend and foe*. Translated from the German by Alistair and Alison Wightman. [Leipzig,] Edition Leipzig, c1987. 175 p., illus. [ISBN 3361001374]

[219] A good general history is contained in: R. Collison., *Encyclopaedias: their history throughout the ages. A bibliographical guide with extensive historical notes to the general encyclopaedias issued throughout the world from 350 B.C. to the present day*. Second Edition. New York and London, Hafner Publishing Company, 1966. xvi, 334 p., illus., index.

present about the natural world is derived from the authors of the Classical age. This is as it should be, because nature played an important and vital role in life. Many of these compendiums described animals, plants, and stones, and because they were the writings most easily available, they works became the basis for most mediaeval natural studies, including those attached to minerals.[220]

### 3.3.1 Isidore of Seville (6th Century)

Isidore of Seville[221] was both a prolific and versatile writer. His voluminous output is said to be the beginning of Spanish literature. He was not an original or independent writer, however. Instead, he was a hard working compiler who attempted to collect together all existing knowledge. His best known writing, is the comprehensive *Etymologiae*, or *Origins of Words* as it is sometimes called. Written in the sixth century, it appeared shortly before Isidorus' death and is the culmination of a lifetime of scholarship and research being a vast warehouse of all the learning possessed at the time, which Isidorus had gathered, systematized, and condensed into a single large work. For centuries it was the most used textbook in educational institutions of the Middle Ages. So highly was it regarded as a depository of classical learning that in a great measure, it superseded the use of the individual works of the classics themselves. Not even the Renaissance seemed to diminish its authority with the text being printed at least ten times between 1470 and 1529.[222]

The authority of the *Etymologiae* was well deserved. It furnishes abundant evidence that the writer possessed an intimate knowledge of the Greek and Latin authors, quoting in all one hundred and fifty-four Christian and pagan writers. Many of these he had read in their original which is fortunate since several of the works cited are no longer extant. He also writes his entries in a clear and concise style that is very admirable. This combined to build the great popularity of Isidorus' work, which in turn gave rise to many imitatitions, some inferior, some excellent.

Isidore divided his material drawn from all aspects of human knowledge into twenty books. The science he covers is broad and includes discussions of mathematics, astronomy, medicine, anatomy, geography (giving the first map of the world), zoology, meteorology, botany, agriculture, geology, and mineralogy. The various books of Isidorus are as follows:

1. Grammar and metre of the written word.
2. Rhetoric.
3. Dialectic.
4. Medicine and libraries.
5. Law and chronology.
6. Ecclesiastical books and offices.
7. God and of the heavenly and earthly hierarchies.
8. Church and of the sects, of which latter he numbers no less than sixty-eight.
9. Languages, peoples, kingdoms, and official titles.
10. Etymology.
11. Of man.
12. Of beasts and birds.
13. Of the world and its parts.
14. Of physical geography.
15. Of public buildings and road making.
16. Of stones and metals.
17. Of agriculture.
18. Of the terminology of war, of jurisprudence, and public games.
19. Of ships, houses, and clothes.
20. Of victuals, domestic and agricultural tools, and furniture.

In the sixteenth book, Isidore gives information related to mineralogy. The descriptions are copied largely from Julius Solinus, which had been derived from Pliny, and he devotes special attention to the derivation of the names of the stones, minerals, gems, and fossils described. They are for the most part incorrect, and in some cases fabulous, such as *aurum* (gold) that Isidore says

[220] Zonta, M., "Mineralogy, botany and zoology in medieval Hebrew encyclopedias: 'Descriptive' and 'theoretical' approaches to Arabic sources," *Arabic Sciences and Philosophy: A Historical Journal*, **6** (1996), 263-315.

[221] Isidore of Seville or Isidorus Hispaleisis (Born: Cartagena, 570 c.e.; Died: Seville, Spain, 636 c.e.) was for some thirty years Bishop of Seville. He was canonized in ??????.

[222] Bibliography ...

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is derived from *aura* (air) because it is by the air that the splendor of the metal is reflected in our eyes.[223]

### 3.3.2 Theophilus the Monk

Theophilus the Monk, to distinguish him from Theophilus the Alchemist is thought to have written his encyclopedia, *Diversarum Artium Schedula*, probably towards the end of the eleventh century or at the start of the next. Based on incidental information contained in the work, the author is presumed to have also been German in origin. Nothing else of the author is known for certain. His work is a compendium of arts and crafts taken primarily from Greek and Egyptian sources, with traces of Byzantine and Arabic influences. It is of considerable value to the historian of technology and science, containing full descriptions of the subjects it treats, which in other works were only briefly described.[224]

The *Diversarum Artium Schedula* is divided into three major sections. The first treats the manufacture, preparation, and use of various paint pigments, as well as pottery glazes. Accounts are given of the raw materials required and the recipes used for making the glazes and other pigmentation, together with other techniques of chemical preparation that had no parallel until the chemistry texts of the fourteenth century. The second section gives a full description of glass manufacture, describing how various kinds of glass plates, flasks, and colored glasses are made. Directions are also given for painting and gilding glass articles, by fusing the colors or gold to the glass in a special furnace. Artificial colored gems and their polishing are carefully described. The final section describes the refining of metal and various techniques in metal working that takes up nearly half of the text. This part is of special interest because it fully describes many ancient and early medieval techniques that are only vaguely described by other authors. It contains the earliest European account of bell founding, and other procedures it described were not bettered until the writings of Biringuccio and Agricola of the sixteenth century.

Any mineralogical content is purely incidental to the other material Theophilus describes. Yet, there are numerous snippets in the text. Gold is said to be obtained from along the shores of the Rhine river, where the sand of the beaches is placed on wooden tables and water carefully and frequently poured over it, to separate the metal. The preparation of mercury from its native occurring cinnabar is accomplished by placing the mineral in a flask, which is then placed in a strong heat.

### 3.3.3 Alexander Neckam (1157-1217)

Another writer who deserves special mention here is Alexander Neckam[225] (1157-1227), who was one of the most remarkable English men of science of the twelfth century. In him we have a curious link between the history of science and ordinary secular history, for he was the fosterbrother of King Richard the First of England (Coeur-de-Lion). In a chronicle formerly existing among the manuscripts of the Earl of Arundel it is recorded that "In the month of September 1157 there was born to the King at Windsor a sone named Richard and the same night was born Alexander Neckam at St. Albans, whose mother gave suck to Richard with her right breast and to Alexander with her left breast." He received his early education at the Abbey School of St. Albans and later studied at the University of Paris, where he became a professor in 1213. His relation to the King who was a lover of learning explains, in part at least, the brilliant position which Neckam achieved in later life. While still bound by a reverence for authority, he sought for something more satisfactory than the teaching of the schools and frequently shows a leaning toward experimental science. Neckam in his book has a long satirical discourse on the logical teaching of the schools of the University of Paris and especially on the quibbles and

[223] Adams, *Birth and Development of the Geological Sciences*, 1938, p. 138.

[224] Bibliography ...

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[225] Alexander Neckam ...

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falsities into which, in the scholastic teaching, logic continually degenerated. Wright who edits Neckam's book and supplies an interesting and valuable preface to the volume, remarks that Neckam gives a number of examples of this he shows how, by the train of reasoning employed in the schools, a man-Sortes the man of straw employed in the language of the scholastic disputations-might be proved to be a stone, or a rose, or a lily, or any other object; how what Sortes or any other individual said was at the same time true and false; how Sortes at the same time knows something and knows nothing; and a number of other similar quibbles.

Reference ...[226]

Neckam's book' was intended to be a manual of the scientific knowledge of the time but has an additional interest from the introduction of many contemporary stories and anecdotes illustrating the conditions and manners of the age. He draws from almost every scientific fact which he mentions a moral or religious lesson or application, although these are often far fetched and their truth by no means very apparent. His book abounds in stories of animals and plants. He mentions the metals briefly and refers to a dozen minerals or stones but does not describe them. Concerning mercury he remarks:

Quicksilver is necessary in gilding; at first the substance of the gold appears to be totally absorbed by the quicksilver, but afterward, by the agency of fire, the quicksilver is consumed and the colour of the gold comes out in all its brightness. So the mind is not gilt with the gold of wisdom without the agony of tribulation and sometimes the beauty of wisdom appears to have entirely disappeared in the tribulation until it is submitted to the solace of the Holy Ghost, represented by fire, and then the strength of wisdom returns to its brightness.

Like most people in the Middle Ages, Neckam believed that gems and precious stones possessed extraordinary virtues. Thus in referring to agate he repeats the statement made by Marbodus, to the effect that the agate (achates) carried on the person rendered the bearer amiable, eloquent and powerful, and he explains the story of Aeneas having a faithful companion named Achates by supposing that he carried with him an agate stone whereby he acquired the love of many people and was rescued from many dangers.

[226] Adams, *Birth and Development of the Geological Sciences*, 1938, p. 138-40.

### 3.3.4 Bartholomæus Anglicus (c1200-1247)

Bartholomæus Anglicus[227] While older authorities give precedence to the Basel edition, printed by Ruppel, it can now be stated that this is the first printed edition of Bartholomæus, since the early manuscript dates found in two Ruppel books have been shown to be forgeries, and as it now seems that Ruppel did not begin printing in Basel until after 1472.

Reference ...[228]

Besides being the first printed edition, this Cologne issue is important for its connection to William Caxton. The Cologne city ledgers record that Caxton arrived in the city in July 1471 (Birch) to learn the process and art of printing. In 1471, Johann Veldener chose Bartholomaeus' encyclopedia as his first project, and accepted Caxton as his pupil. However, indications are that Caxton's role was considerably more important as a financier. The necessary capital is more likely to have come from Caxton than Veldener who had only recently achieved independence by the establishment of his own printing office and who therefore would have been close to the limits of his financial capacity. Under these circumstances, would he have dared on his own to venture the publication of so large a book? There is the further possibility that Veldener got together the necessary funds by charging the Englishman for instruction in the art of printing (Corsten). Thus this edition is the earliest example of Caxton's printing.

De Proprietatibus Rerum was the most popular encyclopaedia of the thirteenth cen-

[227] Bartholomæus Anglicus ...

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[228] Adams, *Birth and Development of the Geological Sciences*, 1938, p. 140-1.

tury, which has been called the age of encyclopaedias. The intellectual renaissance of the preceding century had stimulated a desire for learning. It was impossible for a large number of students to acquire first hand knowledge of every science and the universities could not accommodate all those who wished to learn. Therefore some means of spreading knowledge was required. The problem was solved by writing encyclopaedias that collected together the opinions of the best known authorities. These works varied in comprehensiveness and arrangement, but the educational aim was never forgotten. These books were to be used as textbooks and works of references for the preachers and scholars that did not have access to a library and who could not afford to collect one of their own. In fact, Bartholomæus wrote his compilation primarily for the student of theology and for the preacher as he explains in the Prohemium.

De Proprietatibus Rerum was written as an ordered encyclopedia of all the sciences of the time: theology, philosophy, medicine, astronomy, chronology, zoology, botany, geography, mineralogy, are the subjects treated in this work. It is the first important encyclopedia written in the Middle Ages and the first in which the works of Greek, Arabian, and Jewish naturalists and medical writers, which had recently been translated from Arabic into Latin, were included as contributions. Aristotle, Hippocrates, Theophrastus, the Jew Isaac Medicus, the Arabian Haly, and other researchers are frequently quoted. Even in the age before mechanical printing, the De Proprietatibus Rerum enjoyed widespread popularity as is shown by the many dozens of manuscripts still in existence. In manuscript form, it was translated into five European languages: French, English, Spanish, Provençal and Italian. Thus, it had a widespread appeal to the general population and had a great influence on the cirriculum of the medieval university.

Bartholomæus based the structure of his book on the Etymologiarum Libri Duo written by the learned theologian, Isidore of Seville between 623 A.D. and 633 A.D. The 20 sections found in Isidore are reduced and rearranged to 19 by Bartholomæus; however, he follows his own method in compiling the observations and adheres to the accepted medieval form of quoting ancient authorities. Sprinkled throughout the text are his own observations that give the De Proprietatibus Rerum a unique flavor.

The 19 books of Bartholomæus' text are ordered thusly:

1. God.
2. Angels and Demons.
3. Of the Soul and Reason.
4. Of the Body's Essences.
5. The Human Body and Each of its Parts.
6. The Ages of Man (Family Life and Household Economy).
7. Of Infirmities and Medicines.
8. Of the World and the Heavenly Bodies (Cosmology and Astrology).
9. Of Time and the Divisions of Time.
10. The Material, Form, and Properties of the Elements.
11. Of the Air and its Natural Phenomena (Meteorology).
12. Of Winged Creatures.
13. Of Waters and Fish.
14. Of the Earth and its Features.
15. Of its Provinces (Political and Economic Geography).
16. Mineralogy, including precious and semiprecious stones, sand, coal, Bezoar stones, etc.
17. On Plants and Trees (A Herbal).
18. Of Animals.
19. On Non-Essential Characteristics (i.e., Colors, Tastes, Odors, etc.), and a Miscellany on Food, Drink, Eggs, Weights and Measures, Music, and Musical Instruments.

This ordering which can be classified into four distinct sections suggests that Bartholomæus carefully planned his work.

The order of the De Proprietatibus Rerum is founded on a medieval logic of progression. The first three books form the first section with God, as the supreme creator and the prime moving force, with angles, demons and the soul all occupying the first position. Next comes the second part (books 4-7) devoted to the important factors that affect the life of man. The third section (books 8-18) treats the universe and may be subdivided into two parts. The first (books 8-13) has

as its subject the world in general while the second (books 14-18) describes the earth in particular, including in book 16 metals, stones and minerals. The fourth section is composed solely of the nineteenth book in which everything not previously discussed finds a place including colors, odors, liquids, weighs, measures, music, etc. Since this work was intended as a reference to show mans place in God's universe, the text provides examples of good and bad conduct, and illustrates for him the principals of Christianity.

Since the greatest importance was assigned to theological matters, it became fairly simple for Bartholomæus to ignore the accuracy of his descriptions. Hence we find him with no clear idea of the locations of Egypt or India, the latter being a vague term which medieval men used to refer to the vast territory that stretched beyond Arabia. Bartholomæus' own eyes would have told him that bees do not carry small stones to weight them against the wind, and that crabs do not employ stones to keep oyster shells propped open while they dine on the contents. It was as obvious then as now that the legs of a fox are not shorter on the right side, and that swiftly moving currents are not the cause of oars becoming disjointed in appearance when dipped under water. Yet we cannot blame him for being a man of his time.

### 3.3.5 Thomas Cantimpré (1200-1270)

Thomas Cantimpré[229] Thomas of Brabant. Thomas Brabantinus, de Cantiprato, Cantipratanus, Cantimpratensis. Flemish Dominican and encyclopaedist. Born in Brabant c. 1186-1210 (probably nearer to the latter date, c. 1204?); flourished in Chantimpre, near Cambrai; studied in Li6ge; entered the Dominican Order in 1232; was in Paris in 1238; subprior in Louvain, 1246; died, probably in Louvain, c. 1271-1280. It is possible that he attended some of Albert the Great's lectures, but he can hardly be called the latter's disciple. His two main works are (1) a popular encyclopaedia of science, De natura rerum, to the preparation of which he devoted some fifteen years of study and which he completed between 1228 and 1244; (2) a collection of absurd stories for the edification of the clergy, Bonum universale de apibus, written late in life.

Reference ...[230]

Another writer whose work is but little known is the Dominican Thomas Cantimpratensis, who was born at Brussels in 1201 and died between 1263 and 1280. He resided for many years at Cambrai, from which place he derives his name. His encyclopedic work entitled De Natura Rerum, was never printed, but several manuscripts of it exist, one of the most perfect being in the Staatsbiliothek in Munich. He describes about 70 minerals, the number varying somewhat in the different manuscripts, and enlarges on the occult properties of the precious stones, but adds nothing to the work of earlier authors from whom his information is derived. According to Valentine Rose a number of the trade names for certain stones, as for instance corneolus, granatus and rubinus, first appear in this book.

It is interesting to observe that the Dominican, Thomas of Cantimpre, and the Franciscan, Bartholomew the Englishman, were engaged in the same kind of undertaking about the same time: The Properties of things being completed c. 1230-1240, and the Nature of things c. 1228-1244. Both works were encyclopaedic in scope and divided into nineteen books, but they were otherwise very different, and in all probability independent. Judging by the number of MSS., both works were almost equally popular (if one takes into account that there are many MSS. of Thomas' work which do not bear his name); but with regard to printed editions, Bar tholomew's popularity was incomparably greater. Indeed Thomas' encyclopaedia has not yet been entirely published.

Thomas' main authorities were Aristotle, Pliny, Solinus, Ambrose and Basil, Isidore, Adelard of Bath (whom he does not mention), James of Vitry, two lost works, Liber rerum and Experimentator, which were probably

[229] Thomas Cantimpré ...

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[230] Adams, *Birth and Development of the Geological Sciences*, 1938, p. 141.

contemporary or at any rate recent, and a few others to be quoted presently. The De natura rerum is divided as follows:

1 The human body; anatomy, physiology, gynaecology, derived from Galen, Cleopatra, Ibn Sina, William of Conches.
2 The soul, mainly after Augustine.
3 Strange races of man, hermaphrodites, gymnosophists, Brahmans, etc. (a sort of anthropological treatise).
4 Quadrupeds.
5 Birds.
6 Marine monsters, including an account of herring fisheries.
7 Fishes.
8 Snakes.
9 "Worms," including amphibians, leeches, tortoises, etc. (these 6 zoological books, 4 to 9, fill more than half of the whole work).
10 Ordinary trees.
11 Aromatic and medicinal plants and trees.
12 Herbs (the main authority here is Matthaeus Platearius).
13 Fountains and rivers.
14 Precious stones (mainly derived from Marbode); includes the description of a mariner's compass of the floating type.
15 Seven metals (gold, electrum, silver, copper, lead, tin, iron); includes allusions to the transmutation of metals and to the use of lead for plumbing.
16 Seven regions of the air and their humors.
17 The sphere and seven planets.
18 Meteorology.
19 Universe and four elements.

Some MSS. have an additional book (20) De ornatu coeli et eclipsibus solis et lunae, derived from William of Conches. The structure of this work can be summed up thus: (1-3) man; (4-9) animals; (10-12) plants; (13) waters; (14-15) stones and metals; (16-18) astronomy, astrology, meteorology; (19) elements. A very logical plan, and extremely different from that of Bartholomew.

### 3.3.6 Vincent of Beauvais (1190-1264)

Vincent of Beauvais[231] Another of the great encyclopedias is the *Speculum Mundi* by Vincent of Beauvais written between 1240 and 1264. In the general prologue he says that there are a multitude of books and time is short and furthermore man's mind cannot gather in and retain all that the books set forth, therefore he had determined to condense all knowledge into one great work. It is indeed a great compilation in which he quotes from 450 writers by name, some of whom are now known only by the "excerpts" which he gives from their writings. In the brief portion dealing with minerals and rocks he seems to have added nothing to the observations of former writers. The work went through many editions: that in the Osler Library, which is one of the earliest, was printed "not later than 1478." Among the writers whom he quotes most frequently is the almost unknown writer of a very early encyclopedia, Arnoldus Saxo, [4] whose work De Finibus Rerum Naturalium was written between 1220 and 1230. In it the section on stones consists of an annotated list in alphabetical order of 81 names, and is in turn taken from Albertus Magnus, "Evax," Dioscorides and certain Arabic writers.

In the field of encyclopaedia-making, Vincent of Beauvais's Speculum mains was undoubtedly the outstanding achievement of the Middle Ages. Vincent was born about i tgo, became a Dominican at Paris by 1220, was appointed a lector at the monastery of Royaumont by Louis IX about 124.8, and died at Beauvais in 1264. The Speculum, a vast conspectus of the knowledge of the Middle Ages, was the last major work of its kind: after this, encyclopaedists began to compile for a wider public than the very limited world of religious communities, and it would also be true to say that the latter no longer retained the almost complete monopoly in scholarship which had been responsible for the theological framework within which each devout and monastic encyclopaedist had naturally felt obliged to work. It must be added that Vincent relied heavily on the research of his colleagues for many of his quotations from the outstanding works of the past (such as Adelard of Bath's Qgestiones naturales), plagiarized Isidore of Seville at times, and

[231] Vincent of Beauvais ...

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imitated Bartholomaeus Anglicus.

Vincent's great work must not be confused with his Speculum vel imago mundi which he had written some time before, though it is possible that he used the earlier work as a starting-point. The Speculum maius was first completed in 124.4, and was continually subject to revision by Vincent until his death. It comprises four books, of which the last-the Speculum moray-was added early in the fourteenth century by another, unnamed author. The contents of the four books are:

I. SPECULUM NATURALE.

1. God, divinity, angels, devil.
2-8. The Creation: the first three days-used as a vehicle for physics, geography, geology, agriculture, alchemy
9-14. Botany
15-22. The Creation: fourth to sixth daysastronomy, weather, birds, fishes, animals (in the order in which they appeared on earth according to the Book of Genesis), and animal husbandry
23-28. Man: soul and body
29-31. God and man
32. A resumé of the Speculum historiale

II. SPECULUM DOCTRINALE.

1-3. Language (including a glossary), grammar, logic, rhetoric
4-10. Ethics, family life and economics, politics, law
11-12. Crafts, architecture, war, sports, navigation, hunting, agriculture, applied medicine
13-17. Medicine, physics, mathematics, metaphysics, theology.

III. SPECULUM HISTORIALE.

1. Summary of the Speculum naturale and of the Speculum doctrinale
2-31. A world history to 1244, based mainly on Pierre le Mangcor's Historia scholastica (c. i i 6o), covering Biblical, secular and cultural matters.

IV. SPECULUM MORALE.

Ethics, astrology, and theology (based principally on St Thomas Aquinas).

The Speculum doctrinale was originally planned to form part of the Speculum naturale, but the size of the work–and the demand for copies of specific sections-convinced Vincent that the formation of a separate division for the arts and sciences was advisable. In the same way, the inclusion of summaries of the individual Specula in each other enabled the requests for complete sets to be reduced somewhat-Vincent even published a separate ' epitome of the Speculum historiale which he called the Msmorialt:

The Speculum mains served as the world's only major encyclopaedia for many years afterwards, and even today it remains of inestimable importance as the only repository of excerpts from some works which no longer survive, as a mirror. to the state of knowledge during the thirteenth century, and-what is equally important-as a record of the cultural tastes and prejudices, of those times. It was responsible for the introduction of many quotations now in common use, and constituted the main source of such classics as the Roman de la rose, the Alexander romances, Colonna's Liber de viris illustribus, and of the lives of the saints as they are known, as well as one of the many sources of Boccaccio's Genealogia deomm, and The travels of Sir John Mandeville. In addition, it is invaluable for the history of Vincent's own lifetime.

Translations of parts of the Speculum mains were made into French, Spanish, German, Dutch and even Catalan, and innumerable epitomes, borrowings, plagiarisms and plunderings were its inevitable lot for the next two centuries at least.

Johann Mentelin of Strasbourg and his son-in-law Adolf Rusch (the 'R' printer), printed the first editions about the years 1472 to 1476. Mentelin printed the first, third and fourth Specula, while Rusch printed the first three, complete sets being made up from the combined products of the two printing-houses. The Speculum historiale was also printed at the monastery of Saints Ulrich and Afra at Augsburg in 1474; the Speculum naturale by the Printer of the Golden Legend at Strasbourg about 1481; and the Speculum morale by Winters at Cologne about 1477. The earliest editions are best: during the next 150 years the text became increasingly corrupt as the scholars of the day amended-not always for the bestthe excerpts from Vincent's ggo sources in accordance with the contemporary editions of these works.

Even so, the earliest printed editions are all

based on a fourteenth-century manuscript and there is need for a new critical edition which is now being undertaken by Professor Berthold Louis Ulman on behalf of the Mediaeval Academy of America.

### 3.3.7 Lumen Animæ (c1300)

A late 13th- or early 14th-century encyclopedic work attributed to Berengarius de Landora and sometimes wrongly attributed to the Viennese Carmelite monk, Matthias Farinator [fl. 1477], who compiled the index and edited the text. The *Lumen Animae* is a curious handbook of illustrative sermons for preachers, to explain the natural and moral world. Collison gives the following descripton: "The anonymous Lumen Animae, compiled about 1300, comprises two books of 75 titles and 267 chapters respectively. These chapters are arranged in rough alphabetical order. The materials collected in them are drawn chiefly from patristic sources or moral writers, and there are few items dealing with the natural sciences." This first printing was the work of Anton Sorg.

The anonymous Lumen animae, compiled about 1300, comprises two books of 75 titles and 267 chapters respectively. These chapters are arranged in rough alphabetical order. The materials collected in them are drawn chiefly from patristic sources or moral writers, and there are few items dealing with the natural sciences. The 75 titles of the first book include moral and didactic items, and some attention is paid to scientific information. Some thirty years were required for the compilation of this encyclopaedic work which was addressed to Pope John XXII. The editio princeps was issued by Matthias Farinator, a Carmelite of Vienna, under the title Light of the soul, or Book of the moralities of great natural things (Augsburg, Anton Sorg, 1477), and was reprinted in the same year. Further editions were issued by Michel Greyss (Reutlingen, 1479), and by the Printer of Legenda Aurea (Salzburg, 1482).

### 3.3.8 Konrad von Megenberg (?-1374)

Konrad von Megenberg[232] between 1349 and 1351 composed his *Das Buch der Natur* as a free translation of the *De Natura Rerum* of Thomas Cantimpratensis or Thomas of Cantimpré, although Konrad thought the source text to be the product of Albertus Magnus' youth. It also has material taken from Aristotle and Galen, coming through Arabian conduits. It is the first work of natural history that appeared in the German language, and was apparently a popular early book around Augsburg, the city where all the incunabula editions were published, the first coming from the press of Johann Bämler, was dated 1475. It states on the title page that it was translated ("transferiert") from the Latin into German, probably a reference to the Latin text of Thomas Cantimpratensis. The content is reordered somewhat in this German version with other original material added, making it a book worthy of study because it presents a full picture of the medieval notion of the natural world. Megenberg, however, recognized that some of the statements in his book were open to doubt, eventhough they were considered to be from sources of the highest authority, and in many instances he states he does not believe them.

*Das Buch der Natur* is divided into eight sections, which has at the beginning of each book is an introduction describing the various classes.

1. Von dem Menschen in seiner gemainen Nature, 50 chapters, describes human anatomy, physiology and interpretation of character from physical signs and dreams.
2. Von den Himeln und von den siben Planêten, 33 chapters, descibes astronomy and meterology.
3. Von den Tiern in ainer Gemain describes animals in

[232] Konrad von Megenberg (Born: Megenburg (or Mainberg), near Schweinfurt, Germany, 2 February 1309; Died: Regensburg, Bavaria, Germany, 14 April 1374) was a German scientist, theologian and historian. The dates of birth and death are not absolutely certain, and Konrad himself calls his native place Megenberg. His father was probably a bailiff or overseer in the old castle of Mainberg. Conrad studied liberal arts in Erfurt, and then went to Paris, where he became a magister and studied and taught theology and philosophy. He remained in Paris from 1329 to 1337, then he went to Vienna where he was director of the St. Stephan School. In 1342, he transvered to Ratisbon (Regensburg), where he became a parish priest, then a canon of the cathedral. He remained there until his death, and is buried in the Benedictine nunery of Nieder-Münster in Regensburg.

general, including 69 chapters on quadrepeds, 72 on birds, 20 on the creatures of the sea (e.g., crocidile, seal, dolphin, hippopotamus, sirens), 29 on fishes, 37 on snakes, 31 on 'worms' (i.e., insects, toads, frogs, snails, leeches, spiders, earthworms).

4. Von den Paumen, 84 chapters, describes trees.
5. Von den Kräutern, 89 chapters, describes plants and herbs.
6. Von den edlen Stainen, 86 chapters, describes precious stones.
7. Von dem Gesmaid, 10 chapters, on various metals, including gold, silver, Gunderfai (electrum), copper, tin, lead, and iron, quicksilver, orpiment, and sulphur.
8. Von den wunderleichen Prunnen, describes the wonderful properties of streams and waters and with human monstrosities.

In the 6th section of the book, "Von den edlen Stainen," are treated the gems, their color, their properties, both real and imagined, together with suggestions on how to increase their mystical powers. Eighty-six stones are described, some of them being quite fabulous as for instance the Terobolen, which are said to be "Stones which come from the orient, some of them presenting the form of a man and others that of a beautiful young woman. If they are brought near to one another they send forth flames and fire."[233] Also the Dyadochos, a stone that when thrown into water causes spirits to appear who will answer questions that are asked of them.[234] Animals and plants did not escape Megenburg's attention and the book contains many wonderful stories about them as well, which helped make it very popular to the general reader. Also enhancing the text are the numerous and wonderful numerous woodcut illustrations, which no doubt contributed to its popularity.

### 3.3.9 Domenico Bandini (c1335-1418)

The humanist Domenico Bandini[235] wrote his gigantic encyclopaedia, the *Fons Memorabilium Universi* by filling most of his leisure time with the project until he died. It was divided into five parts in honour of Christ's wounds:

Part I. Theology.

1. God.
2. The angels.
3. The soul.
4. Hell, the Devil, and his demons (includes an added treatise on the art of magic).

Part II. The Universe and Astronomy.

1. The world.
2. The heavens.
3. The stars and constellations (alphabetically arranged).
4. The planets (alphabetically arranged).
5. The seasons, and chronology.

Part III. The Elements.

1. The elements in general .
2. Fire.
3. Air.
4. Weather.
5. Birds; animal husbandry.
6. Seas and oceans.
7. Lakes, rivers, marshes, streams and fountains.
8. Fish.

Part IV. The Earth and its Geography.

1. Provinces and regions, including the theory of politics and government
2. Islands
3. Cities and towns, ancient and modern
4. Notable buildings, and miscellaneous items
5. People and customs
6. Mountains
7. Trees and vines; wine-making
8. Herbs, vegetables, etc. g Quadrupeds
9. A tractate on the eating of flesh, fish and fowl
10. Reptiles and worms
11. Gems and precious stones
12. Metals (and an added treatise-in some copies-on alchemy)

Part V. Man and his Conduct.

1. Famous and illustrious men
2. Philosophical sects-and a world chronicle to 1315
3. Theological and moral virtues and vices
4. Some medical remedies
5. Heresies and heretical sects 6 Famous women.

[233] Konrad von Megenburg., *Buch der Natur*. Stuttgart, 1861, p. 465.

[234] Konrad von Megenburg., *Buch der Natur*. Stuttgart, 1861, p. 444.

[235] Domenico Bandini (Born: Arezzo, Italy, c1335; Died: 1418) spent his life teaching at Florence, Bologna, and in his native city. He came into close contact with the new humanism during his years in Florence, and was in touch with Coluccio Salutati, the leader of the movement.

Bandini's encyclopaedia is remarkable for its numerous cross references, particularly in the sections devoted to historysand . geography. It is possible that some of the work may have been written by his son and literary executor, I.orenzo Bandini. This huge encyclopaedia of secular learning was, designed:';xo provide educated men who lacked books with accurate information on any subject, and with edifying lessons to guide them in their lives. It was widely read in his own country until the middle of the fifteenth; century, but then fell into neglect for about three hundred years.

The outstanding feature of the Fons is Book i of Part V, the De viris clans virtuts nut vitio, which is especially strong in information on Latin authors. The majority of people mentioned are in fact classical figures and their lives are based on classical sources, but there is some original material and much of interest in the selection and treatment of the subjects. It has been suggested that the De viris was intended to be an epitome of the Foes. The Fons has never been published-apart from brief extracts-but many manuscripts have survived.

### 3.3.10 Gregor Reisch (c1467-1525)

Gregor Reisch[236] and his *Margarita Philosophica* published in Freiburg in 1503 is a popular and much reprinted work, being the first modern encyclopedia to appear in print. Handled in the form of a dialog between teacher and student, the book was written as a textbook to be consumed in a university curriculum, and provides an overview of many subjects. Reisch divides the text into twelve books, each explaining one of the sciences:

1. Grammar.
2. Dialectic.
3. Rhetoric.
4. Arithmetic.
5. Music.
6. Geometry.
7. Astronomy.
8. Principles of Nature Philosophy (de principiis rerum naturalium).
9. Origin of Natural Objects (de origine rerum naturalium) containing references to minerals, metals and mining.
10. Psychology.
11. Logic.
12. Ethics.

The twelve editions published in the 16th century attest to its popularity. The book was very sought after on account of its comparative brevity and popular form, and was for a long time a customary textbook of the higher schools. Alexander von Humboldt said of it that it had "for a half-century, aided in a remarkable manner the spread of knowledge".

The volume is notable for several other reasons. It contains the first schematic representation of the eye, and its plate of the human brain, localizing psychological features in specific regions of the brain, is demeaningly discussed by Vesalius because it relates the three ventricles of brain to three specific functions. This diagram roughly shows the convolutional pattern of the brain and depicts the classic medieval representation of localized psychology. The numerous woodcuts show medical subjects, a mineral spring bath used by both sexes, earthquakes, scenes from the lifes of differenent professions, monsters, beasts, fishes, comets, mining of metals and minerals. There is also a depiction of an alchemist working in his laboratory on the transmution of metals.

The large woodcut map of the world is an interesting combination of fact and fancy, mixing the Ptolemaic world with mideaval belief. It has no border, but is surrounded by twelve heads with inscriptions representing and naming the different winds. It shows Europe, Asia and Africa, whose coast line extends along the bottom side of the map until it joins with

[236] Gregor Reisch (Born: Balingen, Württemberg, Germany, c1467; Died: Freiburg, Germany, 9 May 1525) Reisch became a student at the University of Freiburg in 1487 and received the degree of magister in 1489. Then he entered the Carthusian Order. During the years 1500-1502 he was prior at Klein-Basel, and from 1503 to shortly before his death he was prior at Freiburg. Reisch was confessor of Maximilian I. He was also visitor for the Rhenish province of his order. In this capacity he made many exertions to combat Lutheranism. He became friends of the most celebrated Humanists of the time, e.g., Erasmus, Wimpfeling, Beatus, Rheananus, Udalricus Zasius, and the celebrated preacher, Geiler of Kaisersberg. Reisch developed a good reputation for adaptability and his knowledge was so broad and profound he became regarded as an 'oracle.'

Asia. Marks around the edge indicate longitude and latidue. The New World is not shown, although an inscription beneath the unfinished continent of Africa indicates a knowledge of the American discoveries. This map measures 300 x 411 mm. (11 x 16.5 inches) and is extremely rare and often lacking from the book for the obvious reason that it is to large to easily have been bound up.

The Strassburg printer Schott [see note below] was specially brought to Freiberg to print this work. There he established a by-press so that Reisch could oversee the publication of his work.

### 3.3.11 Arnoldus Saxo (c1225)

Recognized as one of the first encyclopedists of 13th century, Arnoldus Saxo[237] At the beginning of the Renaissance he was a privileged witness to the transmission of the Greek-Arabic works to classical Latin, becoming a tool of that transmission himself.

Recent research places during the medieval period the activity of Arnoldus Saxo as the author of several works touching upon natural philosophy and morals in 13th century. In an 1885 study, Emil Stange identified him as the likely author of a small encyclopaedia *De Floribus Rerum Naturalium*.[238] Subsequently, Stange edited a critical edition of the encyclopedia that was its first appearance in print.[239] Consequently, Arnoldus is recognized as one of the sources for natural science of the thirteenth century.

Like his near contemporaries Albertus Magnus, Vincent of Beauvais, Bartholomaeus Anglicus and Thomas Cantimpré, Arnoldus used as his foundation a common corpus of sources for his text. As an author however, Arnoldus is especially useful in his description of stones and minerals that constitutes the most original part of the work since it is not presented in the form of interlacing citations.

Except the studies of Stange, few studies devoted to Arnoldus Saxo have appeared. When it was studied interest in Arnoldus' encyclopedia has usually been in connection with its heavy use of quotations from Aristotle's works on which about a one third of its text is based.[240] Another recent study has recently thrown light on Arnoldus' encyclopedic work.[241] Otherwise, little research has evolved since Stange's critical edition of the encyclopedia published in 1905-1907.

The text of the encyclopedia is divided into five parts. The first 'De celo and mundo' is devoted to a study of cosmology, where metaphysics is joined to physics in the structure of the scale of the causes. Five books distribute the subject respectively:

1. The first cause and the heart.
2. Stars and planets.
3. Elements and their distribution in the animal world and vegetable.
4. Meteorology.
5. The mineral world.

The second part 'De naturis animalium' describes the corruption and generation in the animal world, in the order adopted by the majority of earlier encyclopedists: man, quadrupeds, birds, fish, reptiles.

The 'De virtutibus lapidum' as written by Arnoldus presents in its first book an alphabetical stone catalogue, accompanied by descriptions of the stones properties and their virtues with emphasis on their therapeutic or prophylactic nature. The second book 'De sigillis' the class according to sculptures' which

[237] Arnoldus Saxo (Arnold of Saxony or Arnoldus Luca) [Rikmersdorf near Helmstädt, Germany, c1316; Halberstadt, Germany, 8 July 1390] is a German naturalist, probably a doctor and teacher, who was undoubtedly widely read for his time. *Refs.* DBA, I 11, 206-211; II 16, 124, 124a, 125a-128. • DSB, **1**, 93-95. • Mayerhöfer, *Lexikon der Naturwissenschaften*, p. 167-168. • NDB, **1**, ??. • Poggendorff, **1**, col. 24. • Sarton, *Introduction*, **2**, pt. 2, 592. • *World Who's Who in Science*, p. 24.

[238] Emil Stange., *Arnoldus Saxo, der alteste Encyklopadist des XIII. Jahrhunderts.* Dissertation. Halle, 1885. 67 p.

[239] Emil Stange., *Die Encyklopadie des Arnoldus Saxo zum ersten Mal nach einem Erfurter Codex herausgeben.* All three parts appeared as *Beilage to Jahresbericht of the Königliches Gymnasium in Erfurt.* (I) "1905, Progr. Nr. 278," (II) "1906, Progr. No. 289" and (III) "1907, Progr. Nr. 289."

[240] Thorndike, *History of Magic*, **2**, 260, 431-432, and 469-470.

[241] Isabelle Draelants., "Introduction à l'étude d'Arnoldus Saxo et aux sources du De floribus rerum naturalium," (pp. 85-121), in: C. Meier, ed., *Die Enzyklopädie im Wandel vom Hochmittelalter zur frühen Neuzeit.* Internationales Kolloquium des Teilprojekts D des SFB 231 der Univ. Münster, 04.-07.12.1996. Münster, 2002.

confer the virtue of talismans to them. The third book is very short and present in only a few of the preserved manuscripts. This part (De coloribus gemmarum) is devoted to the colors of gemstones and provides information similar to the material found in the works of *Speculum Naturale* of Vincent of Beauvais, book 8 and of the *De Mineralibus*, book 2, of Albertus Magnus. In 1875, Valentine Rose studied the book of the stones and compared its descriptions to lapidaries supposed to be the work of Aristotle.[242] Besides Aristotle, the text relies upon Dioscorides, the Christian lapidaries and 'Evax' (i.e., Marbode) for its descriptions of minerals and gems. Arnoldus' work was probably used by Thomas of Cantimpré, Albertus Magnus, and Vincent of Beauvais, but was not quoted except by the last named and by the anonymous author of the *Hortus Sanitatis*. There is also an anonymous Hebrew translation of it, *Sefer ha-abanim*. Bartholomaeus Anglicus' lapidary is more elaborate than Arnoldus' suggesting that it was perpared at an earlier date.[243]

The fourth part 'De virtute universali' describes the virtues resulting from the universal force to form the whole of the animate and inanimate world. The final part 'De moralibus' defines the virtue, its divisions and the places where it is exerted such as happiness, time, life, death, eternity.

### 3.3.15 Hrabanus Maurus[244]

Hrabanus Maurus (ca. 780-856), abbot of Fulda and Archbishop of Mainz, was theological and pedagogical writer. He was born at Mainz about 776 (or possibly 784) and died near there in 856. His name, which is spelled in various ways (Hrabanus, Rabanus, Rhabanus, Reabanus, Raban, Rabano), is connected with Old High German hraban, "raven"; "Magnentius", which sometimes appears before his surname, Maurus, is probably related to his residence in Mainz. At an early age he became a Benedictine monk at Fulda. In 802 he went to Tours to study theology and the liberal arts, under the great scholar Alcuin, from who he received the surname Maurus after the favorite disciple of St. Benedict. After a year of study, he was recalled to Fulda, where he taught at the monastic school and eventually became headmaster. In 814 he was ordained as a priest; in 822 he became abbot of the monastery. Under Abbot Hrabanus, the monastery flourished, becoming a renowned seat of learning in the Frankish kingdoms. Between 840 and 847 Hrabanus became embroiled in royal political struggles, resigned as abbot, and fled from Fulda. In 847, after a reconciliation with the king, he was appointed Archbishop of Mainz.

Reference ...[245]

Hrabanus was said to be the most learned man of his age. His knowledge of scripture, patristics, canon law and liturgy was without compare. The scope of his writing extended over the entire field of sacred and profane learning as then understood. He wrote commentaries on nearly all the books of the Old Testament, as well as the Gospel of Matthew and the Pauline Epistles. He also wrote more secular works such as De computo, a treatise on numbers and the calendar; the Excerptio de arte grammatica Prisciani, a treatise on grammar and his famous encyclopedia, De rerum naturis.

*De Rerum Naturis* (On the Nature of Things), also known as *De Universo*, is an encyclopedia in 22 books, covering a large range of subjects. It was written between 842 and 847. Hrabanus' stated intent was to compile an encyclopedic handbook for preachers. He drew on earlier sources for his information, particularly the *Etymologiae* of Isidore of Seville, but the organization of the material was his own invention.

Rabanus Maurus's *De Rerum Naturis* (On the Nature of Things), also known as *De*

[242] Valentin Rose., "Aristoteles 'De lapidibus' und Arnoldus Saxo," *Zeitschrift für deutsches Altertum und deutsche Literatur*, **18** (1875), 321-455.

[243] Sarton, *Introduction*, **2**, pt. 2, 592.

[244] Possible references include: *The Jewish encyclopedia; a descriptive record of the history, religion, literature, and customs of the Jewish people from the earliest times to the present day*. Compiled by Isidore Singer and Cyrus Adler. New York, London, Funk & Wagnalls Company, 1901-06. 12 vols. • Samuel S. Kottek., "Precious stones in Jewish and Christian medieval literature: natural and/or occult sciences?", *Koroth*, **16** (2002), p. 89-110. •

[245] Adams, *Birth and Development of the Geological Sciences*, 1938, p. 138.

*Universo*, is an encyclopedic compilation which he assembled between 842 and 846. The earliest edition was edited and printed by Adolf Rusch (the so-called "R-Printer") about 1466. This edition was reprinted by George Colvener in his collected edition of Rabanus's works in 1627, and again by J.-P. Migne in the series Patrologia Latina in 1851.

The books and chapters of the *De Rerum Naturis* are listed below (based on Schipper).

1. *On God and angels.*
2. *On man, the patriarchs, the status of man.*
3. *????????.*
4. *People of the New Testement, martyrs, clerics, monastics, heretics.*
5. *????????.*
6. *????????.*
7. *????????.*
8. *On animals.*
9. *On astronomy - the world and the heavens.*
10. *On time and the calendar.*
11. *On water - oceans, rivers, floods.*
12. *On geography - the regions of the Earth, the globe, paradise.*
13. *On geography - mountains, valleys, deserts.*
14. *On architecture and building.*
15. *On the liberal arts.*
16. *On language.*
17. *On geology - stones, minerals, gems, metals,* De pulueribus et glebis terra; De glebis et aquis; De lapidibus vulgaribus; De lapidibus insignioribus; De marmoribus; De ebore; De gemmis; De margaretis; De christallis; De vitro; De metallis; De auro; De aere; De auricalco; De electro; De stagno; De plumbo; De ferro.
18. *On number, music, medicine.*
19. *On agriculture.*
20. *????????.*
21. *On textiles and clothing.*
22. *????????.*

## 3.4 Books of Secrets[246]

**REWORK:** The books of secrets tradition has not been treated in any comprehensive fashion, despite the fact that they were among the most widely read works of the medieval and Renaissance periods. Since the tradition it treats contains a large number of texts and fragments of texts (as well as, undoubtedly, hitherto undiscovered texts), it can not be described completely.

Although the literature of secrets was present in the West from the 12th through the 16th century and beyond, it did not at any stage in its history have a place among the official sciences. *Secrets* referred to two types of phenomena: those which occurred unexpectedly as a result of some unknown, or occult cause; and those which occurred by artificial rather than natural causes. *Scientia*, on the other hand, aimed at revealing certainty about the physical world as it existed by nature. Secrets were idiosyncratic, in that they were peculiar to a relatively narrow class of phenomena, or could be affected only by some special insight, skill, or cunning, whether that be of the artisan or the magus. For these reasons, knowledge of secrets was restricted. They could be neither understood nor explained according to the ordinary canons of logic and natural philosophy. They occurred spontaneously, without evident cause, and hence lay outside the boundaries of official science.

Nevertheless, the existence of a sizeable literature on the subject tended at various times to raise uncomfortable questions about the limits of knowable and of *scientia* itself. Medieval philosophers could not help but notice, for example, that many secrets attributed to known authors bore a striking similarity to beliefs and superstitions held by the ordinary folk. Normally, authority itself provided the stamp of approval, distinguishing truths based on established, written authorities from false opinions circulating among the people through an oral tradition. But the professional activities of the physician or craftsman often turned up events which could be proved neither by reason nor authority. In such instances, experience alone had to be one's guide.

### 3.4.1 The Literature of "Secrets"

[246] Further historical information may be found in: J. Ferguson., *Bibliographical notes on histories of inventions and books of secrets.* London, Holland Press, 1981. 2 vols. in one. • S.J. Williams., *The secret of secrets: the scholarly career of a pseudo-Aristotelian text in the Latin Middle Ages.* Ann Arbor, University of Michigan Press, c2003.

## 3.4 Books of Secrets

**REWORK:** Books of secrets were not, perhaps, what the term itself might conjure up in the imagination. To the modern reader expecting to encounter some mysterious, arcane wisdom, these works are bound to be disappointing. What was revealed, typically, was not the lore of ancient sages or magi, but recipes, formulae, and 'experiments,' often of a fairly conventional sort, associated with one of the crafts or with medicine: e.g., quenching waters for hardening steel, recipes for dyes and pigments, instructions for making drugs, and 'practical alchemical' formulae such as a jeweller or tinsmith might use. When a medieval or sixteenth century writer claimed to have discovered a 'secret,' he often had this meaning in mind; and when a contemporary library catalogue referred to a 'book of secrets,' it usually indicated a compilation of such recipes.

The connotation attached to books of secrets was not completely neutral, however. They were not regarded with the same detachment that we would have, for example, for a cookbook or formulary, the closest modern equivalent of such a work. For one thing, behind books of secrets stood a long tradition of anonymous and pseudonymous writings that purported to reveal the esoteric teachings of famous philosophers. The best known of these works was the pseudo-Aristotelian *Secretum Secretorum*, an Arabic work that was translated into Latin in the 12th century and is found in about five hundred manuscripts dating to the seventeenth century! The core of this work is a handbook on statecraft in the form of a letter from Aristotle, the prince of philosophers, to Alexander the Great, the prince of princes. By a process of accretion, however, it gradually became an encyclopedic work encompassing rules for the preservation of health, medical diagnostics and recipes, physiognomy, medical astrology, a herbal, a lapidary, and an extended discussion of the occult sciences. Insofar as this work can be said to promote a philosophy, it was the view that the secrets of nature are revealed only to those worthy of them; and that with the aid of this knowledge, all things are possible in the material world.

The *Secretum Secretorum* was obviously a medieval classic, but its influence on science has yet to be fully evaluated. Roger Bacon edited the Latin text of the work and made extensive notations, and may have caused him to shift his interests from philosophy to *scientia experimentalis*.

The popular tradition of secrets in literature was written for the masses, not scholarly persuit. Despite the scorn of the scholars, however, the popular literature capitalized on the prestige associated with the great scholars of the past. Almost all the ancient scholars have works spuriously attributed to them. This is not suprising when one realizes that the intellectual climate constrained many scholars of the medieaval age to cast their writings in the form of commentaries on the works of the ancients. For example, the whole of Albertus Magnus' vast output was intended by the author to be a commentary on Aristotle, though it ultimately contained much original work from Albertus. The *Book of Secrets* attributed to Albertus Magnus was one of the most widely known works in a literature that gained popularity during the Middle Ages. The popularity of this work is demonstrated by the survival of a large number of manuscripts from as early as the 12th century and by the fact that several continued to be copied, anthologized, translated, and printed well into the 17th century.

As its Latin name, *Liber Aggreationis*, or "book of collected items", suggests, The *Book of Secrets* is an anthology rather than a single work. The treatment of the subject matter is also sensational, reinforcing the popular myths about nature. It is divided into sections describing the marvellous properites of herbs, stones, and beasts. However, within each part the text is collected from a wide variety of sources. The text may be divided into these component parts: (1) On Herbs describes 16 herbs described in terms of their magical properties, (2) On Stones repeats 45 entries from Albertus Magnus' Mineralia, which is followed by a single paragraph taken from the 7th century encyclopedist, Isidore of Seville, (3) On Beast, in which 18 beasts—

animals, birds and fish are described, and (4) On the Astrological Influence of Planets containing a treatise on the hours of the day governed by the various planets. In later editions another formerly independent treatise describing "The Marvels of the World" is sometimes appended.

Although the preface and a passage at the end of the section dealing with beasts attribute this as an original work of Albertus Magnus, it is very different from the other known writings of him. It was written, however, contemporary with Albertus or shortly after he died; the earliest surviving manuscripts are from the late 13th century, and Albertus died in 1279. It may be that The Book of Secrets was written by a follower of Albertus; certainly, as Thorndike writes, "There can be little doubt that it pretends to be a product of his experimental school among the Dominicans at Cologne."

## 4.0 Agricola and his Time[247]

By the mid-point of the second millennium, around 1500, nature and science came under intense review by the intellectuals and philosophers. The ancient explanations of physical phenomena that had persevered for centuries simply did not stand up against what was being observed in the world. Church dogma, an authority that had once been absolute saw its power crumble as its doctrines were shown to be flawed. Into the vacuum created flowed new ideas and theories based upon practical observation and presented in scholarly books written by keen observers. It was one of the most dynamic times in science.

## 4.1 Mining in Saxony[248]

The ancient lands occupied by the Celtic peoples extended across all of Europe and contained the territories of Eastern and Western Europe, and the British Isles. They were excellent workers of metals, especially gold, as is known by the marvelous artifacts that have been found in their graves. Raw material was probably recovered from placer deposits from all regions under their control, including present day Hungary, which lies to the southeast of Saxony. They also build up extensive trade between their people and the surrounding societies that brought in other raw mineral material. Later, as the Romans expanded their Empire into central Europe they were continually looking for new sources of metals, and actively created complex mining technologies to extract mineral wealth from the earth. This is well documented by the discovery of ancient dewatering wheels at the ancient Roman mines of Rio Tinto in Spain.[249] Although the mineral wealth of Saxony were not know until long after the Roman Empire fell, the techniques they introduced to the mining process remained. Vestiges of its technologies remained through out its former European domains.[250]

[247] Further historical information may be found in: Walther Fischer., *Mineralogie in Sachsen von Agricola bis Werner. Die ältere Geschichte des Staatlichen Museums für Mineralogie und Geologie zu Dresden (1560-1820).* Dresden, Verlagsbuchhandlung C. Heinrich, 1939. viii, 348 p., 24 plates. • Hans Prescher and Otfried Wagenbreth., *Georgius Agricola - seine Zeit und seine Spuren.* Leipzig, Dt.Verlag für Grundstoffindustrie, 1994. 234 p., 94 illus. • Arthur J. Wilson., *The living rock. The story of metals since earliest times and their impact on developing civilization.* Cambridge, England, Woodhead Pub., 1994. xix, 291 p., illus., maps, portraits. [Published as a Festschrift in honor of the quincentenary of the birth of Georgius Agricola, 1494-1555, the 'Father of Mineralogy'.; ISBN 1855731541.]

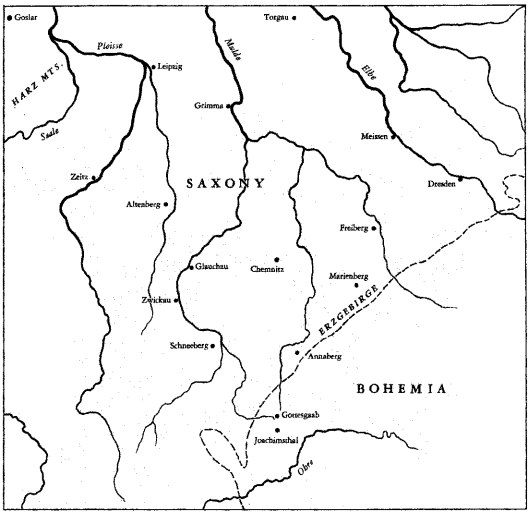
[248] Further historical information may be found in: Anonymous., *Studien zur Geschichte des Montanwesens in Sachsen vom 16. bis 19. Jahrhundert.* Leipzig, Deutscher Verlag für Grundstoffindustrie, c1989. 106 p., illus. [History of mining in Saxony 1500 to 1900. Published as: *Freiberger Forschungshefte, D* **194**.; ISBN 3342009942.] • Oliver Davies., *Roman mines in Europe.* Oxford, 1935. xii, 291 p., 4 plates, illus., maps (3 folding). [Reprinted, New York, Arno Press, 1979.] • J.C. Edmondson., "Mining in the later Roman Empire and beyond," *Journal of Roman Studies*, **79** (1989), p. 84-102. • W. Liessmann., *Historischer Bergbau im Harz: Kurzführer.* Köln, Sven von Loga, 1992. 320 p., illus. [A history of mining in the Harz Mountains of Germany. Published as: *Schriften des Mineralogischen Museums der Universität Hamburg*, vol. **1**.; ISBN 3873612429.]

[249] G.D.B. Jones., "The Roman Mines at Riotinto," *Journal of Roman Studies*, **70**, (1980), p. 146-165. • T.A. Rickard., "The mining of the Romans in Spain," *Journal of Roman Studies*, **18** (1928), p. 129-143.

[250] P. T. Craddock., *Early Mining and Metal Production.* Washington, Smithsonian Institution Press, 1995. • O. Davies., *Roman Mines in Europe.* Oxford, Clarendon Press, 1935. • J.C. Edmondson., "Mining in the later Roman Empire and beyond," *Journal of Roman Studies*, **79** (1989), p. 84-102. • R.J. Forbes., *Studies in Ancient Technology.* Leiden, E.J. Brill 1963, vol. 7. • John F. Healy., *Mining and*

## 4.1 Mining in Saxony

Thus it happened that during the Dark Ages, the territory of Saxony came under the control of the Germanic tribes. This mountainous region in the southeast of modern Germany is particularly rich in ores of several useful metals such as tin, copper, and silver. Mines in the Harz mountains of Saxony became active in the time of Charlemagne (742-814 c.e.). Operations in the Saxon mines, just as in those of the Greeks and Romans, were carried out by slaves. With no power tools or explosives, tunneling through the hard rock was slow and difficult with daily progress probably only inches per day. New mines were found in neighboring areas, like the Erzgebirge range separating Saxony and Bohemia. Eventually these mines became the most prosperous in all Europe.




Main area of Saxon mining

Landowners opened their estates to prospectors who had becme adept at looking for minerals. Some of these prospectors were former serfs. A prospector staking a claim could sell the minerals he found after paying a royalty to the landowner. Mine owners became financiers and creditors of the royal courts of Europe. Certainly, gold was recovered from regions further south, in the ancient province of Dacia (modern Transylvania and Hungary). But Bohemia and Saxony appear to have only minor mineral exploitation until the eighth century.

Mining was established in Bohemia at Přibham and at Schemnitz by the eighth century (probably around 750 c.e.). Gold mining in the Tavern, which had been operated for a long time before the Romans by the Celts is again worked in 908 c.e.. In 930 c.e. ore is discovered near Rammelsberg and Goslar and mines are opened. Around 1000 the first section of the "Kupferschiefer" (copper sheet) is developed and mined, and in about 1100 tin and silver veins are discovered at Freiberg. Albertus Magnus visited the silver mines there doing his travels in the following century.

By the mid-fourteenth century mining through out the region of Saxony was in full blossom. It was the principal industry of the area and was supported by ancillary smelting and mining works. Surprisingly, there appears to be no evidence of theoretical speculation as to why so much mineral wealth was concentrated in the area. It was taken for granted that the mines would continue to deliver minerals and metals to the Saxon economy, as the area already had for centuries. This nonspeculative attitude would change over the next centuries, however, as new ideas took hold.

The major change from the casual magical attitude toward gems and minerals received its most powerful impetus from the beginnings and development of the great mining industry in the Erzgebirge (Ore Mountains) of Saxony. This range of mountains extended into Bohemia and, as the Harz Mountains, was located west of Saxony and east of this region, reaching into Hungary.

In this comparatively small area mining expanded and the region became one of the most prosperous in all Europe. Families grew rich from the mining operations and this wealth brought great advances in the technology of mining, the processes of ore reduction and the refining of metal. The area also developed a high order of literacy so that a body of theoretical and practical information and experience was gathered and interchanged.

*Metallurgy in the Greek and Roman World.* London, Thames and Hudson, 1978. • T.A. Rickard., "The mining of the Romans in Spain," *Journal of Roman Studies*, **18** (1928), p. 129-143. • R. Shepherd., *Ancient Mining.* London, Elsevier Applied Science, 1993.

Here by the fourteenth century, metallurgy and mineralogy attained true proportions as sciences.

### 4.1.1 The Renaissance

In the 1200s the exceptional figures of Dante, Roger Bacon, Vincent of Beauvais and Marco Polo expanded the frontiers of knowledge of their time. They initiated in Italy a revolution in intellectual thought that spread to other countries. The "Renaissance," adopted from the French equivalent of the Italian word "rinascita," meaning literally rebirth, describes the radical and comprehensive shift that took place across the social, political, cultural, and scientific fabric of Europe during the next centuries. This intellectual trend, also called humanism, or *studia humanitatis*, was at the heart of development in literature, art, and science, which was a fresh alternative to the dark atmosphere of the Middle Ages. It was a period when the first focus was on the restoration of the natural knowledge of the ancients followed by a period of innovation. During this epoch there lived such scientists as Leonardo Da Vinci [1452-1519], the astronomers, Nicolaus Copernicus [1473-1543], Giordano Bruno [1548-1600], Johannes Kepler [1571-1630], Galileo Galilei [1564-1642], and the anatomist Andreas Vesalius [1514-1564].

The astronomers placed the sun at the center of the heliocentric system, which had a tremendous impact on weakening church authority in scientifc matters. The scientists thus looked at the earth, and its animals, plants, and minerals, from a fresh viewpoint. Leonardo Da Vinci in his notebooks formulates the idea of mountains being formed from uplifted sedimentary rock and being destroyed by weathering agents. He also speculates after seeing the first maps of the Atlantic coast lines of South America and Africa, that these land masses were once joined (predating modern plate tectonic theory by centuries).

During the Renissance Aristotle's concept of the round immobile world was fairly well fixed in men's minds. Around the spherical core of the world there rested, like mantles, the three additional Aristotelian elements in order of their weight. Upon the sphere of the earth flowed the mantle of water and over it rested the air and, above this, the sphere of fire.

It was generally accepted that each planet was the source of some great spiritual power reigning over heaven and earth. Not only in astrology but in many of the accepted practices in agriculture, animal husbandry and in most walks of life, the influence of the stars was believed to be of primary importance in shaping the lives of individuals and of nations. The moon was considered the abode of the angels and Mercury that of the archangels. Venus was the seat of the principalities, the sun the center of the powers; Mars was that of the virtues, Jupiter of the dominations, Saturn the center of the thrones, the fixed stars of the cherubim and the Primum Mobile of the seraphim. At birth, the life of a person was predestined by the position and influence of the planets in the sky. Calendars were prepared so that men might be guided by the heavenly signs; astrologers were consulted in the preparation of horoscopes.

This practice reached into mining and metallurgy. The seven common metals were related to the seven planets. Mercury and its "mercurial" characteristics were related to the quick-moving planet named after the swift travelling messenger of the gods. Copper was related to Venus, and gold shone with the yellow warmth of the sun. Silver and the silvery moon were thought of together, and iron, essential to war and the "martial" spirit, was associated with Mars. Jupiter (Jove) and the "jovial" spirit were thought of as relating to tin, and distant Saturn was associated with the dull qualities of lead. The association of planet and metal was carried to the point of using common signs by astronomers and astrologers in the designation of the planets and, later, geologists adopted these signs to represent the corresponding metals.

The ancients judged rocks, minerals and gems entirely by their appearance, and whatever classification was attempted was based on their superficial resemblance. No effort was made to determine the chemical composition or crystallographic structure of minerals. Color and transparency were of primary consideration. Metals differed from minerals in that the former were either fusible

or malleable.

It was stated by Aristotle that the heat and rays of the sun reaching the earth's surface and interior caused exhalations which penetrated the earth's crust, made possible new combinations of elements, created metals and minerals and formed the various kinds of stones. This belief continued into the Dark and Middle Ages and was explained by Albertus Magnus in his *De Mineralibus*. This early treatise on minerals and metals repeats the essence of the celestial influences of the sun, the stars and the planets in creating and changing minerals, metals and stones. Therefore his reiteration of the Aristotelian doctrine of the creating of stones and metals thru celestial influences on earth remained unchallenged until the end of the 1500s.

Ancient views of the underworld continued to dominate. Their speculation of the earth's inside bore no evidence of being based on actual observation, and are instead curious ideas based upon myth and lore. The four elements proposed by Aristotle remained the accepted explanation from which the physical world was build, and descriptions of nature were based in those terms until the middle of the eighteenth century.

The word "fossils", as used in medieval times, applied equally to rocks, minerals or fossils. Its meaning stemmed from the Latin word *fossilis* that described anything dug out of the earth. As the arts and sciences of mining and metallurgy advanced, distinctions arose and three sub-sciences of mineralogy, petrography and paleontology were applied respectively to the specific science of inorganic substances, the science concerned with the description or classification of rocks, and the science dealing with fossilized plants and animals.

Metals constituted a distinctive part of "fossils" because of their bright luster which distinguished them from other stones and the fact that they could be extracted from the ores by means of fire. According to Aristotle, a metal was a combination of the elements of earth and water, as seen from the fluid character of metals when heated and by their malleability when hammered. The attempts of Albertus Magnus and Thomas Aquinas to coordinate the teachings of Aristotle and those of medieval theology carried the notion of the celestial origin of metals and metallic ores into the literature of scholastic philosophy. Because of this, Aristotle's notions became an integral part of scholastic literature down thru the ages. The invention of printing in the 1450s multiplied and distributed man's knowledge in undreamed of numbers of books.

So recent is the science of geology that the very word Geology or Geologia, used approximately in its present sense, was first used in literature as late as 1605. Similarly the first reference to "geologia" appeared in an English book in 1661.

## 4.2 Technological Heritage[251]

After the wave of Black Death swept across Asia and Europe in the fourteenth century, many events came to pass that had a profound influence on civilization. During the social upheaval, perhaps the most important was that "when the plague was over, . . . everybody was better off in gross terms, since those who survived took what had belonged to those who died."[252] With the rise in living standards, more property began to be exchanged, which meant larger quantities of documents were prepared. This in turn created a heavy demand for skilled scribes, who wrote virtually all of the legal agreements of the period.

Since the plague is transmitted by a bacteria that infects rats, places where close contact with rodents was probable were the places hardest hit by the Black Death. Coincidentally, population centers, such as the towns and monasteries of Europe were also the residences of virtually all the learned men of the time, including the scribes. As a result many of the literate members of the community died in the Plague, thereby allowing those scribes that

[251] Further historical information may be found in: Arthur J. Wilson., *The living rock. The story of metals since earliest times and their impact on developing civilization.* Cambridge, England, Woodhead Pub., 1994. xix, 291 p., illus., maps, portraits. [Published as a Festschrift in honor of the quincentenary of the birth of Georgius Agricola, 1494-1555, the 'Father of Mineralogy'.; ISBN 1855731541.]

[252] J. Burke., *Connections*, 1978, p. 98.

survived to command astronomically prices. To further unsettle the situation, a cheap and easy method of making paper had been established by the end of the fourteenth century. Clearly, there was a necessity to develop a cheaper means to place writing upon the paper, and this method must inevitably be some form of mechanized writing.

### Mechanical Printing

In Europe, an early form of mechanical printing appears in several forms among which are decks of playing cards and several small booklets known as *block books*. These were created by carving a mirror image of what was wanted on the paper into a block of wood, and then using this block to transfer the inked image to the paper. The technique required a great amount of time to carve the block (gross mistakes caused the carver to start over from scratch), which because it was wood, was relatively soft and tended to wear away quickly during the printing process.

A German goldsmith from Mainz is generally regarded as the person who brought great leaps of technology to printing. He was Johann Gansfleisch, but is better known by his mother's maiden name – which he adopted – Gutenburg. He learned the goldsmith trade through his father, who had officiated at the Mainz mint, and his knowledge of how to work metals played a great role in his development of a new method of printing. The principal component missing from developing a true mechanical printing was the invention of a moveable type, and for this Gutenburg had two great assets. He knew how to work metals, and the German alphabet of his time contained only twenty-three letters (no j, v, or w).

Gutenburg recognized the problem was to develop a reusable type that was uniform in size, that could be set side by side to print an even line of text, and that would be made of materials not easily worn down during the printing process. To solve the problem every letter had to be cast into an identical mold, and this is where his knowledge of metals became a necessity. The material from which the mold was made had to have a higher melting temperature than the metal used to make the casting. Additionally, the stem for each letter must be the same height and dimensions, regardless of what letter it represented. The problem was that after the casting had cooled inside the mold, it had to be extracted without breaking the mold. The solution required genius to create the intricate three piece mold that was undoubtedly developed over a period of years. The three pieces slid together like a puzzle and are held together by a large curved spring. After casting the letter, the pieces of the mold could slide apart to extract the cast letter, and then be put back together again to cast another identical letter. It satisfied the requirement that the stems of every letter be the same size. Thus one letter could easily be interchanged with any other in a given line of type, which is what makes moveable type an efficient technology.

Very quickly after Gutenburg introduced his invention, publishing houses appeared in most of the major European cities. The first subjects to be published were by and large the writings of the classical authors or theological books, but as the sixteenth century came, texts of a more practical nature appeared. The printing press made it possible for cheap hand books to be prepared,[253] and the vast amount of practical knowledge concerning all manner of technologies that had been built up over the centuries, and passed from master to apprentice was ripe for dissemination to the eagar reading public. There began to appear at the beginning of the century a new class of literature, used by its practitioners and those aspiring to enter technical professions. It was a literature devoted to the practical application of knowledge with illustrative examples, with essentially no theoretical discussions. These technical booklets were designed to give useful information as to how to accomplish specific tasks. They were apparently widely popular, especially in the German communities, as is indicated by the large number of titles published on a wide selection of subjects and of which numerous editions appeared. These books were also apparently much read as the

[253] Partington, *History of Chemistry*, 1964-71, **2**, p. 32-114.

few surviving copies show tremendous wear from their years of service.

### 4.2.1 Bergbüchlein (c1505)[254]

The *Bergbüchlein* (Little Book on Ores) that appeared about 1505 is the first in a long series of printed books, dedicated to the mining arts. It is a practical handbook designed for beginners rather than experts in the field of mining, and as an introduction to mining geology, which means that it was not addressed to the practicing expert but was intended to rouse the interest of beginners in the various aspects of a future vocation. The booklet comprises instructions from Daniel, a skilled miner, to Knappius, 'his mining boy'. In ten chapters, the work contains an introduction to mining geology, touches on some theories of the generation of ores, which is of mineralogical interest, introduces and defines many of the important technical terms of the profession, discusses the ores of the seven most important metals, and how to prospect for them. Not all the information contained in its pages is based on fact or even first hand knowledge of the author but enough of the material was sufficiently practical for Agricola to have used it as a reference book and even copied certain passages verbatim in writing his more comprehensive work. It touches on the theories of the generation of ores, introduces and defines some of the most frequently encountered technical terms of the profession, and indicates what knowledge and tools are required for successful prospecting and mining. It also describes the ores of the seven most important metals. For those parts that deal with theory the author accepted uncritically the traditional teachings of the alchemists and the astrologers; his hints on where to find promising ores are based partly on superstition; but there is enough factual, practical information, for example, on veins and their differences, on the occurrence of a metal in different ores, and on the association of a specific ore with others or with certain gangue materials, so that even a scholar like Agricola used the *Bergbüchlein* as a reference book.

Actual authorship of the *Bergbuchlein* is unknown, but based on circumstantial evidence is attributed to 'Calbus of Freiberg, a well-known doctor', i.e., Ulrich Rülein von Calw.[255] Indeed Rülein is accepted by present-day scholarship as the author, although most editions of the Bergbuchlein were published anonymously.

### 4.2.2 Probirbüchlein (c1510)[256]

The *Probierbüchlein* (Little Book on Assaying) that appeared about 1510 is the first printed work on any aspect of assaying, displaying the art fully developed as it applied to gold and silver, and to a lesser degree copper and lead. It is a treatise very important for the history of the development of mineral chemistry. It contained much detailed and accurate information concerning the methods of separating gold and silver from other metals and from one another by so-called cementation processes, but contained no reference to methods depending on the use of the mineral

[254] Further historical information may be found in: Ernst Darmstädter., *Berg-, Probir- und Kunst-Büchlein.* München, 1926. 111 p. [Published as: *Münchener Beiträge zur Geschichte und Literatur der Naturwissenschaften und Medicine* (Heft 2-3). The bibliography describes 80 early books related to mining and assaying.] • A.G. Sisco and C.S. Smith, *Bergwerk- und Probirbüchlein.* New York, 1949. 196 p., illus., biblio. [A translation of two sixteenth century works on mining (*Bergbuchlein*, 1518) and assaying (*Probierbuchlein*, 1534), the earliest printed books on the subjects. With technical annotations and historical notes, bibliography of known editions, etc.] • H. Wilsdorf, *Präludien zu Agricola. I. Das Joachimstahler Bergbüchlein des Hans Rudhart 1523. II. Die Cosmography des Sebastian Münster 1544.* Berlin, Akademie, 1954. 224 p., illus. [Published as: *Freiberger Forschungshefte, Kultur und Technik*, D-5.]

[255] Ulrich Rülein von Calw (or Kalbe) (Born: c1467; Died: Leipzig, Germany, 1523) was appointed the health officer of Freiberg in 1497, before being elected a member of the city council in 1509 and mayor in 1514 and 1519. He is thought to have worked as a mine surveryor, mathematician, astronomer and physician.

[256] Further historical information may be found in: Ernst Darmstädter., *Berg-, Probir- und Kunst-Büchlein.* München, 1926. 111 p. [Published as: *Münchener Beiträge zur Geschichte und Literatur der Naturwissenschaften und Medicine* (Heft 2-3). The bibliography describes 80 early books related to mining and assaying.] • A.G. Sisco and C.S. Smith, *Bergwerk- und Probirbüchlein.* New York, 1949. 196 p., illus., biblio. [A translation of two sixteenth century works on mining (*Bergbuchlein*, 1518) and assaying (*Probierbuchlein*, 1534), the earliest printed books on the subjects. With technical annotations and historical notes, bibliography of known editions, etc.]

acids. It was intended to be used as a practical guide for the assayer, and is a compilation of the accepted practices and recipes that must have been developed over a long period.

This little book provides many detailed directions describing the apparatus and furnaces used in preparing the ores, separation of one metal from another, and other processes related to metallurgy and assaying. It covers everything from making touch needles, furnaces, crucibles, cupels, and weights to compounding fluxes and reagents and prescriptions for their use. Also of interest is the fact that the manufacture of various balances for the laboratory seems to have been well developed, because the text refers to the importance of accurate weighing. In fact a later edition of the *Probierbüchlein* (1533) gives woodcut illustrations of these balances.

### 4.2.3 Biringuccio (1540)[257]

In this new era metallurgical works were further developed in central Europe. Innovative techniques were tried, and the results published in widely circulated books. Popular handbooks on mining and assaying began to appear. The interest in metallurgy is reflected in the work of Vannoccio Biringuccio. In his 1540 *Pirotechnia*[258] that consists of ten sections, Biringuccio describes the different metals and their ores, deriving much about the theory of their origin that is derived from Aristotle, methods of locating ores, and their properties, including comments about sulfides, the action of sulfur, alum, oxides, halite, and many other substances. He fully describes methods of ore processing, melting and refining of metals, glass manufacture, separation of silver from gold, and preparation of nitric acid. He gives many practical procedures, that were well adopted to metallurgical operations, and gives descriptions of the various apparatus necessary including furnaces, bellows, balances, and the like. Biringuccio also comments on the increase in a metals weight during calcination (i.e., forming an oxide).

## 4.3 Georgius Agricola[259]

The time was ripening for an intelligent man, with an inquisitive and practical nature to bring a new, fresh insight toscientific views of the geological world. On March 24th, 1494, at Glauchau, Germany, just such a man in the person of Georg Bauer was born to a local dryer and woolen draper. However, in writings of later years, he would Latinze his name to Georgius Agricola, by which he is today best remembered. In his youth he attended various primary schools in Glauchau, Zwickau, and Magdeburg, and in 1514 he matriculated at Leipzig University. In 1515 he received his first degree, and stayed at the university as lecturer in elementary Greek. In 1517, he took a position at Zwickau, where he taught Latin and Greek in several schools.

Zwickau, as a center of the Lutheran Reformation, caused Agricola to evaluate his religious belief. He came to believe that a reformation was necessary, but did not care for the revolution championed by the Lutheran supporters and remained catholic. Therefore, in 1523 he returned to the more moderate Leipzig to study medicine and in 1524 he travelled to Italy for additional studies in philosophy, medicine and the natural sciences at the ancient universities at Bologna, Padua and Ferrara, finally taking his degree in medicine at one of them. About this time

[257] Further historical information may be found in: O, Johannsen., "Biringuccio und seine 'Pirotechnia'," *Beiträge zur Geschichte Technische Industrie*, **16** (1926), p. 153-61. • James R. Partington., "Biringuccio and Agricola," *Isis*, **26** (1936), p. 37-8. • C.S. Smith., "Biringuccio's 'Pirotechnia' – a neglected Italian metallurgical classic," *Mining & Metallurgy*, **21** (1940), p. 189-192.

[258] Vannoccio Biringuccio., *De la Pirotechnia Libri X.* Venetia, 1540.

[259] Further historical information may be found in: Bern Dibner., *Agricola on metals.* Norwalk, Conn., Burndy Library, 1958. 128 p., illus. [Published as *Burndy Library*, no. 15.] • Walther Fischer., *Mineralogie in Sachsen von Agricola bis Werner. Die ältere Geschichte des Staatlichen Museums für Mineralogie und Geologie zu Dresden (1560-1820).* Dresden, Verlagsbuchhandlung C. Heinrich, 1939. viii, 348 p., 24 plates. • *ibid.*, "Zum 450. Geburtstag Agricolas, des "Vaters der Mineralogie," *Neues Jahrbuch Mineralogie, Geologie und Palaenotologie*, Series A, **1944**, nos. 7-9, p. 113-225, 42 figs., one table. • *ibid.*, "Dr. Georg Agricola," *Zeitschrift der Deutschen Geologischen Gesellschaft*, **96** (1944), pts. 1-3, p. 124-8, one fig. • *ibid.*, "Johannes Mathesius zu St. Joachimsthal (1504-1565)," *Der Aufschluss*, **11** (1965), p. 267-91. • Hans Prescher and Otfried Wagenbreth., *Georgius Agricola - seine Zeit und seine Spuren.* Leipzig, Dt.Verlag für Grundstoffindustrie, 1994. 234 p., 94 illus.

he was befriended by the famous humanist Erasmus, who Agricola met during a visit to Basel. It was Erasmus, who recommended that he be appointed to the editorial staff for the Aldina editions of Galen and Hippocrates.

In 1526, Agricola traveled through the mining districts of Carinthia, Styria, and the Tyrol, returning to Germany in the fall. The following spring he opened an apothecary in St. Joachimsthal (now Jächymov), Slovakia, and was subsequently elected town physician. Here he continued to study the pharmaceutical use of minerals and smelting by-products, with a view to compiling a commentary on the medical texts of Galen and Hippocrates. At the time, St. Joachimsthal was one of the most important mining centers in Europe. The diseases that afflicted the miners and smelters of the region became Agricola's focus of study. Day after day, he visited the mines and refineries, and soon developed a deep knowledge of mining and metallurgy. It was a confluence of man and moment.

There was a great need for a practical mind to organize the techniques and processes employed in the mining technology of the time. The economic activity which came with the Renaissance made it possible for a man like Agricola to enter the mines, to study the structure of the earth's crust and to organize his observations into a logical pattern which evolved into the sciences of mineralogy and geology. It was based on these observations, he recorded his observations in the first of his great mining works, *Bermannus sive de re Metallica Dialogus*, published in 1530. The success of this pioneering work on mining and metallurgy was assured by Erasmus, who contributed a letter of recommendation. The publication of this small book by Froben, one of the foremost printers of the time, was followed in 1533 by another book also by Froben and also at Basel. This was the *De Mensuris et Ponderibus*, a discussion of Greek and Roman weights and measures. It was also at this time that Agricola began to organize and gather the material for his later work *De Re Metallica*, which took some 20 years to write and an additional five years for printing. But after his initial books, Agricola was now a well-known author, and to build on that reputation he needed to make a change.

There were too many demands on his time in St. Joachimsthal, and Agricola made the decision to move to the smaller, quieter mining town of Chemnitz, where he became town physician. Chemnitz was a copper producer that had a smelter which was also used to extract silver from the ore. Agricola's knowledge of minerals and mining enabled him to make profitable investments in the local mining operations. His partnerships were almost always successful, and by 1542 he was one of the town's richest inhabitants.

Beginning in 1546 he published a series of six works on mining, metallurgy, geology and animals used in mining. Continuing his friendship with Erasmus, Agricola remained loyal to the Catholic faith, tho he was surrounded by men who sided strongly with the Reformation. In addition to his metallurgical works, Agricola also published studies in medical, religious, political and historical subjects. These reflect his many interests and a dedicated professional attitude.

His success enabled Agricola to work on what is considered his greatest achievement in science, although this had to take a subordinate postion to diplomatic missions he took on for the court of Saxony. For three years, he was a councillor of Moritz Duke of Saxony, and was one of the few Roman Catholic representatives in the Protestant court. Finally in 1548, he was able to return to his scientific writings, and new books began to appear in the next year: *De animantibus subterraneis* (1549) and an enlarged edition of *De mensuris et ponderibus* (1550).

In 1550, he had with him the finished text of his chief work, *De Re Metallica Libri XII*, begun twenty years before in St. Joachimsthal. He then found in St. Joachimsthal an expert designer Blasius Weffring, who spent the next three years creating woodblock to illustrate the text.

When the plague spread through Saxony in 1552-1553, Agricola worked day and night, attempting to alleviate the suffering of those afflicted. Notes and observations during this time led him to publish his description of the disease in 1554 as his *De Peste Libri III*.

In November of 1556, Agricola fell ill and died. Four months after his death, *De Re Metallica Libri XII*, illustrated with 292 woodcuts, appeared. A year later a German translation by the physician Philippus Bech was published using the same woodcuts. The importance of *De Re Metallica* can be shown by its immediate translation into German and Italian and its subsequent reissue in ten editions. It remained the leading textbook for miners and metallurgists for nearly two centuries. At a time when most industrial processes were held secret by families, guilds or towns, Agricola saw fit to publish every practice and improvement that he considered of value, and to use Latin to gain the widest circulation in his homeland and abroad. He had little to draw on from earlier sources that had any practical value except possibly Biringuccio.

## 4.4 The Influence of Agricola[260]

The period into which Georgius Agricola was born was a remarkable time in human achievement. It was the height of the Renaissance, and Columbus had discovered America just two years before he was born. Luther and Dürer were Agricola's countrymen and contemporaries, and Copernicus and Vesalius had just transformed the universe and dissected man, its most interesting inhabitant. A slumbering world had awakened and Agricola added his voice to acclaim its rebirth.

Agricola to his credit, abandoned inductive speculation in favor of the results of observation. In this respect he was one of the first to prescribe to the theory. This helps explain why so much of his text is devoted to refutation of the many ancient and deep-rooted beliefs of the Scholastics. To Agricola we owe the first adequate declaration of the part played by erosion in the shaping of mountain masses. Similarly no predecessor gave a clearer interpretation of the origin of ore than did Agricola, because in experience and penetrating observation he was among the most gifted in his time. To him also goes the credit for accuracy and clarity in maintaining that ore channels filled the interstices in rocks by the process of deposition from circulating solutions. This was an enunciation of a fundamental modern theory and constitutes one of his greatest contributions to geology and metallurgy.

In mineralogy, the contributions of Agricola were mainly in classifying minerals on the basis of the properties of solubility and homogeneity in addition to those of color and hardness. This was still a long way from the radical changes that followed chemical and crystallographic analysis of the late 1700s. He also was the first to add bismuth and antimony to the list of true primary metals. Similarly, to the 60 actual mineral species known in his time, Agricola added 20 new ones, thus increasing the original number by a third.

The rewards of mining technology and the broad interest in mineralogy attracted alert and inventive minds to the field in which Agricola worked. They gathered data and tried to relate it to broad principles. For example, Christoph Entzelt (*Latin*, Encelius) published a small book on metals in 1551. Buth Agricola's authority was such that his chief selling point was that he claimed to record information *not* to be found in Agricola![261]

Conrad Gesner, another contemporary of Agricola, was born and lived mainly in Zurich in Switzerland, where he, like Agricola, was the city physician (Stadtarzt). He was a prolific writer on plants and animals and his book *De Rerum Fossilium Lapidum et Gemmarum* was printed in 1565, the year of his death, a victim of the plague. It

[260] Further historical information may be found in: Ernst Darmstädter., "Georg Agricola, 1494-1555. Leben und Werk," *Münchener Beiträge zur Geschichte und Literatur der Naturwissenschaften und Medicine*, pt. 1 (1926), 96 p., portrait. • Walther Fischer., "Zum 450. Geburtstag Agricolas, des "Vaters der Mineralogie," *Neues Jahrbuch Mineralogie, Geologie und Palaenotologie*, Series A, **1944**, nos. 7-9, p. 113-225, 42 figs., one table. • H. Hirai., *Le concept de semence dans les théories de la matière à la Renaissance: de Marsile Ficin à Pierre Gassendi.* (doctoral dissertation), University of Lille 3, 1999. [Contains: Agricola, pp. 81-98; Cardan, pp. 99-115; Césalpin, pp. 116-130; Paracelse, pp. 132-161; Palissy, pp. 247-262; Boèce de Boodt, pp. 282-300; de Clave, pp. 305-326.] • Hans Prescher and Otfried Wagenbreth., *Georgius Agricola - seine Zeit und seine Spuren.* Leipzig, Dt.Verlag für Grundstoffindustrie, 1994. 234 p., 94 illus.

[261] Christoph Entzelt., *De Re Metallica.* Francofurti, 1551. [16], 271, [1] p., 5 woodcuts.

was, with a minor exception, the first book devoted entirely to this subject which was illustrated by woodcuts and figures. Stressing the importance of the figures contained in his book, Gesner changed from the classic system oi alphabetically listing minerals by the initial letter of their Latin names; he grouped his "fossils" in accordance with the form of the stone, gem or fossil. He arranged his illustrations in an order of increasing complexity from the simple spherical stones to true fossil complexes. Since the book could not readily be printed in colors, this additional means of identification was largely neglected. Not only was this an improvement over the classic listing by alphabetical arrangement, but Gesner also avoided reference to the magic and miraculous properties of minerals. Although he stated that his book was essentially prepared to stimulate an interest in stones, fossils and minerals and that it was prepared as a work of recreation rather than as a profound study, Gesner reflected the new point of view created by Agricola from whom he borrowed heavily.

Another Swiss native, Theophrastus Bombast von Hohenheim [1493-1541], who called himself Paracelsus[262] initiated substantial changes in the development of chemistry of the time by helping to transform the old alchemy into the science of chemistry recognized today. Trained as a physician, he looked skeptically at the alchemists, but recognized that chemistry could play a useful role in medicine. He introduced "iatrochemistry" (from the Greek, 'iatro', meaning doctor), which marks the begining of chemisty as an independent science. His *Ettliche Tractat Philippi Theophrasti Paracelsi ... von naturlichen Dingen* (1570) is his most direct statement on mineralogy that includes descriptions all types of natural things including turpentine, salt, magnets, sulfur, vitriol, alum, arsenic, the metals, and various minerals. His chemistry revolved around minerals because they are naturally chemical compounds; however, his ideas about the orgin of minerals are charactistic of the period giving fantastic speculation. Following the Arabic authors, for example, he believed that the seven planets influenced the creation inside the earth of the various minerals and metals (DSB; Partington, 1961-70).

The direct influence of Agricola in the realm of metallurgy is also reflected in the activities of Lazarus Ercker and the publication, in 1574, of his treatise on ores and assaying. This was basically a textbook for the practicing assayer. Ercker, chief superintendent of mines and comptroller of the Holy Roman Empire and Kingdom of Bohemia, stressed the economic and commercial aspects of his craft, rather than the theoretical. He amplified the descriptions by Agricola of separating precious metals from copper by liquidation with lead, the smelting of tin, and the production of saltpeter. Ercker, with Biringuccio and Agricola, together represented the published metallurgical knowledge of the 1500s. The instructions and descriptions which they prepared were so factual and accurate that they continued as handbooks for nearly two centuries.

Lazarus Ercker *Beschreibung Allerfürnemisten Mineralischen Ertzt vnnd Berckwercksarten* (1574) Together with Agricola's *De Re Metallica* (1st ed., Basel, 1556), Ercker's treatise is the most authoritative and practical work on 16th century metallurgy and assaying. He provides a systematic review of methods of testing alloys and minerals and of obtaining and refining various metals. Also described are procedures for manufacturing acids, salts and other chemical compounds, including saltpeter and vitriol. Apparatus and laboratory equipment used in metallurgy and assaying as well as detailed accounts of laboratory procedures, all of which had been used by Ercker in his everyday work as inspector of mines.

Ercker was an accurate recorder of facts, not a builder of theoretical systems. He writes with amazing clarity, with completely realistic descriptions of the apparatus used and straightforward instructions for various

[262] Johann E. Hiller., "Die Mineralogie des Paracelsus," *Philosophia Naturalis. Archiv für Naturphilosophie*, **2** (1952), p. 293-331 and 435-478. • Joachim Schroeter., "Die Stellung des Paracelsus in der Mineralogie des 16. Jahrhunderts," *Schweizerische mineralogische und petrographische Mitteilungen*, **21** (1941), p. 313-331. [A study of the Swiss native Paracelsus' influence in sixteenth century mineralogy.]

laboratory operations. His treatment of the subject is basically the same as found in any modern treatise on fire assaying, and in fact his work remained the standard text for several centuries after its first appearance.

In five books Ercker defines assaying and what knowledge the practicing assayer should possess. The first book deals with silver ores, how to distinguish them and the apparatus required to perform accurate tests, and refine the resultant metal. Book two describes the same for gold and its ores, while book three covers copper. Book four concerns lead, bismuth, tin, antimony, mercury, iron and lodestone. Book five describes the preparation of saltpeter and the assay of vitriol from pyrite and alum in the ores of alum.

Georg Meyer *Bergwercks Geschöpff und wunderbare Eigenschaften der Metallfruchte* (1595-7) Only edition. Among the books on mining published in the sixteenth century, the one by Georg Meyer is one of the rarest. In contrast to the works by Agricola, Entzelt. Matthesius, and Ercker, it hardly ever appears on the market. The book is dedicated to the Emperor Rudolph II, the patron of Tycho Brahe and Kepler who was a strong supporter of alchemy. At the beginning is a 4 1/2 page poem in praise of miners. The text is then divided into thirteen chapters dealing with ores, metals, minerals, antimony, mercury, bismuth, sulphur, salt, and saltpeter, with a short section on glassmaking in the last chapter.

Georg Engelhard von Löhneyss *Bericht vom Bergkwerck* (1617) Printed at the author's own press, this work, which ranks with Agricola, is among the rarest of the early mining books. It was the first and only book printed at Zellerfeld, due to the destruction of the press and most of the first edition during the thirty years war. Löhneysen designed the plates, woodcuts and initials, employing as engraver of the cuts the German Moses Thym. The plates illustrate the construction, machinery and work in the mines, the processes of metallurgy, etc. Especially valuable for giving an accurate description of German mining and metallurgical methods at the beginning of the XVII century.

As the mineral resources of the ancient mining centers became exhausted, activity moved northward into Saxon, Norman and Swedish mining centers. In Saxony, the work of Agricola helped establish at Freiberg a central source of mining and metallurgical knowledge and information, later formalized into a definite curriculum. Emphasis on observation and the sharing of information began to replace the secretiveness and mysticism of the earlier craftsmen and writers. Agricola's legacy was to bring in his many writings a new openess that was based upon practical observation, with little or no emphasis placed on mystical qualities. All writers on geological and mineralogical subjects after him, in some measure, followed or ignored his example.

## 5.0 Physical Properties[263]

Minerals are physical objects, formed through complex processes with in the earth. Each mineral species has its own set of physical properties that define its existence. For example, every species has a standard hardness or density that is a physical manifestation of its internal crystal-chemical structure. From the earliest times these properties were used to successfully extract minerals and metals from their host rock. As science developed, minerals became objects of formal study. In an effort to describe their objects, authors frequently would mention a minerals physical look and feel. Eventually, researches got the idea that each mineral species had a set of these characteristics that were different from other minerals, and in fact could be used to identify one mineral type from another. An active effort began to test and record the characteristics of each mineral type, in order to identify the mineral represented in an actual specimen. Soon, tables of these relative values of these characteristics developed, which in turn led to elaborate printed descriptions of the mineral species. Mineralogists were trying to place their study on a foundation of accuracy. Over a succession of trials, they began to develop new, ingenious methods to derive the values placed

[263] Further historical information may be found in: Werner, *Von den äusserlichen Kennzeichen der Fossilien*, 1774, p. ??-?? [Introduction].

in their identification tables. Instruments were invented to make repeated tests on minerals, and from all the experimentation, not unexpectedly, new properties were discovered to even more accurately define a mineral species. These were, therefore, folded into the list of properties that could be used in mineral identification.

## 5.1 Color[264]

**REWORK:** The most obvious property of any mineral species is its color. Sometimes extremely vibrant as with red crocoite or blue azurite, and other times dull, a mineral's color can be a key indicator to identifying its species. As a property, color was probably the first distinguishing characteristic used in mineralogy. It is of course a manifestation of the interaction between wavelengths of visible light with the crystal-chemical composition of the mineral as detected by the human eye. Because it requires a great deal of theory as to how color manifests its presence, the earliest studies simply list the color as a characteristic. It was not until the nineteenth century, when techniques in chemistry developed to develop trace elements, that the actual mechanisim for coloring could be described. In addition, the discovery of radiation and its effect on minerals and crystals led to a broader understanding of how color happens in a mineral.

A reference to something early during the Islamic science ...[265]

1728: Du Fay wrote on the the coloring of artificial gems ( 1728)—(DSB).

Color was one of the most prominent physical characters used by the great Abraham Gottlob Werner in distinguishing one mineral from another. In his *Von den äusserlichen Kennzeichen der Fossilien* (1774), he uses descriptive terms to differeniate the various shades of color he means.[266] He includes a folding chart that lists his eight principal colors together with their subdivisions. Words only however can not always convey the color meant. The approach was improved upon in the works of Werner's students and supporters. For example, in Henri Struve's *Methode Analytique des Fossiles* of 1797, the descriptions are backed up with hand-colored plates illustrating the various colors described, together with degrees of the various hues.

The colors of minerals are said to be dilute or diffuse when the coloriug substance is not recognizable as microscopic inclusions, but is in a condition comparable with that of a dye dissolved in a liquid. Van't Hoff[267] has introduced for this state of affairs the conception of solid solutions, a view which has received universal acceptance.

A number of the diffusely colored minerals are characterized by the great sensitiveness of the color toward high temperature, and even toward daylight; here belonging smoky quartz, amethyst, halite, fluorite, zircon, tourmaline, topaz and others.

As to the chemical character of the coloring substances there exists a wide difference of opinion.

The early attempts at explanation were for the most part only conjectures being supported by few experiments. The great difficulty of

[264] Further historical information may be found in: Edmund Hoppe., *Geschichte der Physik*, 1926, p. 285-291. • Albert Johannsen., *Manual of petrographic methods*, 1918, p. 309-312. • Christel Meier., *Gemma spiritalis. Teil I.* München, Wilhelm Fink Verlag, 1977. 542, [2] p., biblio. [Impressive study of theories and ideas about gems from ancient times through the Middle Ages and Renaissance.] • Kurt Nassau., *The physics and chemistry of color*. Second edition. New York, 2001. [Describes coloring factors in a large variety of natural objects including minerals.; ISBN 0471391069.] • Ulrich Räth., *Zur Geschichte der pharmazeutischen Mineralogie*. Braunschweig, Universität Braunschweig, 1971. 273 p. [Published as: *Pharmazeigeschichtlicher Seminar der Technischen Universität Braunschweig*, vol. 12. Covers the history of pharmaceutical mineralogy.] • Karl Simon., "Contributions to our knowledge of the colors of minerals," *Mineral Collector*, **15** (1909), no. 11, 165-168 and no. 12, 177-181. [Condensed translation by Edgar T. Wherry from the original article published in *Neues Jahrbuch für Mineralogie, Geologie und Paleontologie*, Beilage-Band, **26** (1908), 249-295.; it contains an excellent review of color studies in the nineteenth century.] • Sigmund Skard., "The use of color in literature. A survey of research," *Proceedings of the American Philosophical Society*, **90** (1946), no. 3, p. 163-243.

[265] E. Wiedemann., "Über die Entstehung der Farben nach Nasīr al-dīn al-Tūsī," *Jahrbuch der Photographie und Reproduktionstechnik* (Halle), **1908**, p. 86-89.

[266] Werner, *Von den äusserlichen Kennzeichen der Fossilien*, 1774, p. 97-128.

[267] Van't Hoff, "?????," *Zeitschrift für Physkalische Chemie*, 1892.

proving the existence of inorganic substances as the coloring principles by analysis led to the view that these consisted of unstable organic compounds. Schneider[268] was the first to ascribe the colors of the precious stones to hydrocarbons, and in 1855 he claimed to have established this in the case of colored quartz.

Senarmont[269] artificial coloration of strontium nitrate by an extract of logwood and other similar experiments appear to have promoted the opinion that a large number of mineral colors were produced by organic substances.

Proceeding from this view-point, Levy[270] ascribed the green color of emerald to hydrocarbons, having proved the existence of .09% of carbon and .05% of hydrogen in the mineral. Later Friedrich Wohler[271] showed that the color is to be attributed to minute traces of chromium oxide, and Hautefeuille and Perrey[272] used this compound with success as a coloring agent in the artificial production of emeralds.

1860: Friedrich Eisenlohr[273]

Sandberger[274] obtained in the decomposition of dark zircon a distinct test for copper, and considered the oxide of this metal as the coloring substance. Further investigations were carried on by Wyronboff[275] In his work "On the coloring substances of fluorite," he showed that colored fluorspar, on heating, besides showing phosphorescence, suffered a loss of weight, and that small amounts of carbon dioxide and water could be detected. From this he likewise concluded that an organic substance was the coloring principle. On the other hand Low[276] and Moissan and Becquerel[277] found in specimens from Wolsendorf and in other deep blue varieties free fluorine.

Henri Becquerel[278] further succeeded in coloring previously decolorized fluorite and halite, violet and brown upon the surface by exposure to cathode rays. This phenomenon could certainly not be explained by the theory of organic coloring matter. Forster[279] arrived at results similar to those of Wyronboff; upon heating smoky quartz he obtained a liquid with empyrenmatic odor and a carbonaceous coating, the quartz being decolorized Otto Lehmann,[280] Retgers,[281] and Rosenbusch[282] extended our knowledge of organic and inorganic salts diffusely colored by organic substances. These studies showed that only in exceptional cases are inorganic salts colored by organic compounds. Retgers believing, however that organic substances are to be generally regarded as the causes of the colors, with few exceptions. A totally different standpoint was taken by Weinschenk.[283] He endeavored to piove the universally inorganic character of the coloring agents, assuming, as in glasses colored by metallic oxides, higher or lower, and in part hypothetical, oxides for the natural colors.

In opposition, L. Wohler and Kraatz-Koschlan[284] energetically maintained the organic character of the pigments in a number of minerals. They proved both qualitatively and quantitatively the presence

[268] Schneider, "?????," *Annalen der Physik und Chemie*, **96** (1855), p. 282.

[269] Senarmont, "???," *Compt. Rend.*, **38** (1854?), p. 101.; *ibid.*, *Annales des Physique.*, **91** (1854), p. 491.

[270] Levy, "???," *Annales des Chemie et Physique*, **55** (1858), p. 5

[271] Friedrich Wohler, "???," *Annales des Physique*, **122** (1864), p. 492

[272] Hautefeuille and Perrey, "???," *Compt. Rend.*, **106** (1888), p. 1800

[273] F. Eisenlohr., "Erklär. des Farbenzerstr. A d. Verhaltens d. Lichts in Krystallen," *Annalen der Physik*, **109** (1860), 28 p.

[274] Sandberger, "???," *Neues Jahrbuch*, 1881, p. 258.

[275] Wyronboff, "???," *Bull. Soc. Chim.*, **5** (1866), p. 334.

[276] Low, "???," *Bericht. d. d. Ch. Ges.*, **14** (1881), p. 1114.

[277] Moissan and Becquerel., "???," *Compt. Rend.*, **111** (1890), p. 669.

[278] Becquerel., "???," *Compt. Rend.*, **101** (1885), p. 205

[279] Forster., "???," *Annales des Physique*, **143** (1871), p. 171.

[280] Otto Lehmann., "???," *Zeitschrift für Physikalische Chemie*, **8** (1891), p. 543.

[281] Retgers., "???," *Zeitschrift für Physikalische Chemie*, **12** (1893), p. 600.

[282] Rosenbusch., "???," *Mikrok. Physiogr. d. Min.*, 1892, p. 210.

[283] Weinschenk., "???," *Zeitschrift für Anorganische Chemie*, **12** (1896), p. 375.

[284] Wohler and Kraatz-Koschlan., "???," *Min. und Petr. Mitth.*, **18** (1899), p. 304, 447.

of carbon, hydrogen and nitrogen in zircon, smoky quartz, amethyst, celestite, fluorite, apatite, barite, halite, calcite, microcliue and topaz, considering the preseuce of an organic coloring matter established when the mineral on heating yielded an empyreumatic odor, gave carbon; dioxide in a current of oxygen, and showed phosphorescence during the coloration. Spezia[285] attributed the color of brown zircon to a trace of iron an inorganic substance at the same time admitting the presence of hydrocarbons, and in a second paper brought[286] forward further proof of the inorganic character of the coloring matter, while Weinschenk[287] also adhered to his previous views. Wohler and Kraatz Koschlau were also opposed by Nabl,[288] who had suggested iron sulphocyauatc as the coloring agent in amethyst; by extended analyses he had established the preseuce of sulphur and nitrogen.

A very voluminous literature exists on the subject of blue halite. It has been collected with a fair degree of completeness by Focke aud Bruckmoser.[289] Even in this mineral opinions vary as to the organic or inorganic character of the coloring matter. The fact that the blue color can be produced artificially in several different ways has further led to different views of the constitution of the pigment. Various investigators have succeeded in turning salt blue either by sodium vapor or by exposure to cathode rays, and this has been by some attributed to subhaloides, by others to colloidal solutions of the metal.

Wohler and Kasaruowsky[290] have defended the view that naturally blue halite contains an organic coloring matter. They sought for distinctions between the natural and artificially colored salt, and called particular attention to the difference in the temperature at which decolorization occurs. Further indications of the inorganic character of the color were, however, soon brought forward, and Siedentopf[291] finally succeeded in deciding the uncertainty as to whether it was subhalide or metal, in favor of the latter. With the aid of a very powerful microscope he found in both natural and artificially colored halite the same arrangement and optical character of the pigment.

J. Konigsberger[292] repeated the experiments of Wohler and Kraatz. Koschlau upon smoky quartz. He established the presence of minute quantities of carbon dioxide and water, but obtained only one-tenth the loss of weight they had found, and attributes their higher figures to mechanically held moisture. The coloring substance he considered as nonvolatile, and therefore thought it by no means certain that it was a hydrocarbon. He further cited the work of Lenard and Klatt,[293] from which it follows that thermoluminescence is merely phosphorescence accelerated by heat, and can in no case be considered a sign of the presence of organic matter.

Finally Ernst Anton Wulfing[294] was able to reduce the loss of weight during the decolonization of the smoky quartz by ignition to .0003 per cent, showing thereby that isolation of the coloring matter by distillation is not to be thought of. His most exact measurements showed, moreover, that the optical constants were not noticably influenced by the pigments.

In later years the action of Roentgen, cathode, and radium rays upon minerals have been extensively investigated. Kunz and

[285] Spezia., "???," *Neues Jahrbuch*, 1877, p. 304.

[286] Spezia., "???," *Neues Jahrbuch*, 1900, (2) 344.

[287] Weinschenk., "???," *Min. und Petr. Mitth.*, **19** (1900), p. 144.

[288] Nabl., "???," *Sitz-Ber. Akad Wiss Wien*, **2** (1899); *ibid.*, "???," *Min. und Petr. Mitth.*, **19** (1900), p. 273.

[289] Focke aud Bruckmoser., "???," *Min. und Petr. Mitth.*, **25** (1906), p. 43.

[290] Wohler and Kasaruowsky., "???," *Zeitschrift für Anorganische Chemie*, **47** (1905), p. 353.; *ibid.*, "???," *Mineral Collector*, **13** (1906), p. 120.

[291] Siedentopf., "???," *Ber. d. deut. Phys. Ges.*, **3** (1906), p. 268.

[292] J. Konigsberger., "???," *Min. und Petr. Mitth.*, **19** (1900), p. 148.

[293] Lenard and Klatt., "???," *Annales des Phys.*, **15**.

[294] Ernst Anton Wulfing., "Einiges über Mineralpigmente," *Festschrift H. Rosenbusch*, 1906, p. 49-67.

Baskerville[295] and Lockhart[296] studied the resulting luminescence. Miethe[297] examined the color changes in precious stones produced by radium preparations. Crookes[298] observed that the color of a diamond embedded in radium bromide changed to bluish green He considered possible a superficial change into graphite, and a further alteration of the color of the entire stone by the radiation. In the opinion of the author the color change is probably secondary, arising from the fluorescence vibrations ptoduced by the radium.

Furthermore at high temperatures decolorized minerals when exposed to radium resume their color, and it is similar to the original color only-thus zircon treated in this way returns brown, amethyst, violet, smoky quartz, brown, red, tourmaline, red, rose-topaz, orangered. This returned color, superinduced by the radium rays, disappears in the same way as the natural original color, and such recoloring is independent of the gas in which the mineral may be immersed: finally the nature and state of the coloring substance is not known.

Berthelot[299] showed that amethyst decolorized by heating, regains its violet color on exposure to radium rays. Quartz and glass containing small amounts of manganese behaved similarly, and on this account he referred the color of the amethyst to a slight manganese-content. The color of smoky quartz, green fluorite and emerald, not being restored by these radiations, he considered the coloring agents of these minerals to be organic.

Observations of the chemical action of radium and its decomposition products will no doubt contribute toward the explanation of the mineral colors at some future date, but yet they are not established with sufficient certainty to be of use in this connection.

A paper by Karl Simon[300] offered in 1908 a contribution to the knowledge of the colors of minerals, contained a variety of instructive observations. Cornelio Doelter wrote an entire monograph on the subject of color in precious stones,[301] which was an enlargement of an article he authored on mineral coloring agents in general.[302]

In the 19th century the colour of minerals was studied from only two points of view, namely the absorption of light and polychroism. Since then, advances in crystallography have made it possible to relate the optical properties of minerals to their crystallochemical properties. A.E. Fersman (1937) introduced a distinction between:

1. *Idiochromatism,* in which the color of the mineral depends on its chemical composition and the nature of the atomic bonds in the crystal lattice.
2. *Allochromatism,* in which the colour of the mineral is due to the replacement of certain atoms or ions in the lattice by other atoms or ions of similar dimensions, or else to the spread of inclusions through the lattice.
3. *Pseudochromatism,* in which the colour of the mineral is due to the dispersion of light by the crystal.

Coloration may vary slightly with the temperature of crystallization and the presence of foreign substances in the mother liquid. It may also change when powerful electrical influences (cathode rays, radio activity, ultraviolet rays) act upon crystal atoms and ions, to create new absorption bands. The resulting colors have been the object of many experimental studies, particularly by V. Przibram (1927-1953).

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[296] Lockhart., "???," *American Journal of Science*, 4th series, **8** (1905), p. 95.

[297] Miethe., "???," *Anuales des Phys.*, **19** (1906), p. 633, 1906.

[298] Crookes., "???," *Zeitschrift für Krystallographie*, **42** (1907), p. 315.

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[301] Cornelio Doelter., *Die Farben der Mineralien insbesondere der Edelsteine.* Braunschweig, Sammlung Vieweg, 1915, 96 p., 2 illus. [Reprinted, 1987.]

[302] Cornelius August Doelter. *Über die Natur der Mineralfarben.* Wien, 1915. 15 p. [Reprinted from *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften. Mathematisch-Naturwissenschaftliche Classe* (Wien).]

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1899 J.G. Koenigsberger., "Ueber die färbende Substanz im Rauchquarz", *Tschermaks mineralogische und petrographische Mitteilungen*, **19** (1899-1900), p. 148-154.
1899 Arnold Nabl., "Natürliche Färbung der Mineralien", *T. M. P. M.*, **19** (1899-1900), 273-276.
1899 Arnold Nabl., "Ueber färbende Bestandteile des Amethysten, Citrins und gebrannten Amethysten", *Sitzb. Akad. Wiss. Wien.*, **108** (1899), Abth. II, 48-57.
1899 E. Weinschenk., "Natürliche Färbung der Mineralien", *T. M. P. M.*, **19** (1899-1900), p. 144-147.
1903 Carl Ochsenius., "Blaues Steinsalz", *Centralbl. f. Min.*, **1903**, 381-383.
1904 Hans Dudenhausen., "Optische Untersuchungen an Flussspath und Steinsalz", *Neues Jahrb.*, **1904** (I), 8-29.
1906 Ernst Anton Wülfing., "Einiges über Mineralpigmente" (pp. 49-67) in: *Festschrift für Harry Rosenbusch.* Stuttgart, 1906.
1906 Fr. Focke and Jos. Bruckmoser., "Ein Beitrag zur Kenntniss des blaugefärbten Stein-salzes", *T. M. P. M.*, **25** (1906), 43-60.
1910 C. Doelter., *Das Radium und die Farben.* Dresden, 1910, 133 p.
1911 R. Brauns., "Die Ursachen der Färbung dilut gefärbter Mineralien und die Einfluss von Radiumstrahlen auf die Färbung", *Fortschritte der Min., Kryst., und Petrog.*, **1** (1911), 129-140.

### 5.1.1 Streak[303]

**REWORK:** The streak, or the color of a powedered mineral, is usually obtained by scratching the mineral on an unglazed porcelain streak plate. For some minerals the streak and color are the same. For others, the streak may be quite different from the visible color, as for example the red-brown streak of hematite, which is often a gray to silver-gray mineral in hand specimens. For some species, the combination of luster, color, and streak are enough to permit identification of the mineral. In fact streak is a more reliable indication of the intrinsic color of a mineral than is its general appearance, being less influenced by impurities than by the visible color of the mineral itself. Apparently using the color of the powdered mineral as a means of identification is a very old technique, perhaps because powdered minerals were used in cosmetics and medicine from a very early time. The streak of graphite used in modern pencils is, for example, a practical application of mineral streak.

Moore notes that in Pliny's description of Morochites that streak is used as a diagnostic.[304] Morochites described as leek colored, but its streak white–for so the words 'lacte sudat' seem by commentators generally to be understood– was otherwise called moroxus; and hence has Karsten derived his name for asparagus stone, which he calls moroxite.[305] This rnorochites or moroxus we have already, when speaking of saline substances, found occasion to consider.

Abraham Gottlob Werner in his famous *Von den äusserlichen Kennzeichen der Fossilien* (1774) uses streak as his ninth diagnostic tool in his determinative mineralogy.[306] From Werner's time forward streak is included in mineral descriptions when it is appropiate. By the mid-19$^{th}$ century, virtually every textbook of mineralogy gives a description of the property. Suprisingly, only a few studies on streak have apparently been published in the scientific literature.

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Other possible sources.Check Oxford English Dictionary and the Grimm Brothers Dictionary (Strich).[307]

[303] Further historical information may be found in: Ulrich Räth., *Zur Geschichte der pharmazeutischen Mineralogie.* Braunschweig, Universität Braunschweig, 1971. 273 p. [Published as: *Pharmazeigeschichtlicher Seminar der Technischen Universität Braunschweig*, vol. 12. Covers the history of pharmaceutical mineralogy.]

[304] Moore, *Ancient Mineralogy*, 1834, p. 183.

[305] Pliny, Book 37, 63.

[306] Werner, *Von den äusserlichen Kennzeichen der Fossilien*, 1774, §167.

[307] Jacob Grimm and Wilhelm Grimm., *Deutsches Wörterbuch.* Leipzig, S. Hirzel, 1962-70. 16 vols. [Extensive entomological dictionary of the German language, this is a

Literature

1901 Jacques Schroeder van der Kolk., "Ueber die Farbe des ausgeriebenen Strichs des Bornits," *Centralblatt für Mineralogie*, **1901**, p. 519. [A note on the streak color of bornite.].

1901 Jacques Schroeder van der Kolk., "Der Strich der sogenannt opaken Mineralien," *Centralblatt für Mineralogie*, **1901**, p. 75-80. [A study on the streak of the so-called opaque minerals.].

## 5.2 Specific Gravity and Density[308]

**REWORK:** Modern science defines the specific gravity or density of a substance to be the ratio of its weight in air to its weight in water at 4° C. (39.2° F.). In other words, it is the ratio of the weight of any fragment of a substance to the weight of an equal amount of water. The specific gravity of a mineral, provided it is pure and free from inclusions of solids, liquids, or gases, is a constant quantity. In isomorphous series, or in minerals whose chemical composition differs in different specimens, there is, however, a variation, and this serves as a means of separation.

Specific Gravity or density is a very useful feature with which to distinquish minerals of different types, and in fact is one of the oldest to be used. If two minerals of approximately the same size are hefted, it will become quickly clear to the observer which of them is heavier, and in this way the specific gravity of the mineral is being roughly judged. The density, or specific gravity, of a solid depends, first, upon the nature of the chemical substances which it contains, and, second, upon the state of molecular aggregation. The specific gravity of a mineral species is a character of fundamental importance, and is highly constant for different specimens of the same species, if pure, free from cavities, solid inclusions, etc., and if essentially constant in composition. In the case of many species, however, a greater or less variation exists in the chemical composition, and this at once causes a variation in specific gravity. The different kinds of garnet illustrate this point; also the various minerals intermediate between the tantalate of iron (and manganese) and the niobate, varying from G. = 73 to G. = 53.

The ancient mathematician and theorist, Archimedes was once presented with a problem to determine if an intricate crown was made from pure gold or was alloyed with some other lesser metal. At the time, the only way known to determine if it was pure metal would be to melt the object down and test the metal. While taking a bath, he noticed that his mass displaced a specific volume of water, and he made the connection that knowing the exact volume of an object in proportion to its weight would decisively tell him if the crown was pure gold. If it was in fact an alloy, the density of the object would be less than that of pure metal because the alloying material will have a density less than that of gold. Legend records that at the moment of discovery Archimedes jumped from the tub and ran naked through the streets shouting "Eureka!" (in Greek: it is found!). Measurement of density became a useful tool for determining purity.

In Book 33 of his *Histoire Naturalis*, Pliny speaks of quicksilver (mercury) being the heaviest of all substances, except for gold. Using the principal of Archimides, Arabic gem merchants of the Dark and Middle Ages relied upon specific gravity to determine both the type of gemstone (for example, distinguishing between ruby and spinel), and uncovering imitation stones.[309] Al-Bīrūnī includes careful measurements of the specific gravity of the gemstones and minerals he describes.[310]

In the seventeenth century specific gravity was recorded for a large number of objects, including minerals and gemstones. In 1603 Marinus Ghetaldus published a treatise

reprint of the original 1854-1959 edition, with the original title pages.]

[308] Further historical information may be found in: R. Davies., "Tables of specific gravities", *Philosophical Transactions of the Royal Society of London*, **45** (1748), p. 416-89. [A long list of specific gravities, with a history to the mid-eighteenth century of the subject.] • E. Hoppe., *Geschichte der Physik*, 1926, p. 14-15.

[309] Eilhard Wiedemann., "Beiträge zur Geschichte der Naturwissenschaften VIII. Über Bestimmung der specifizischen Gewichte," *Sitzungsberichte der Physikalisch-medizinischen Sozietät in Erlangen*, **??** (19??), p. 240-257.

[310] Wiedemann, E., "Arabische specifische Gewichtsbestimmnungen," *Annalen der Physik*, **20** (1883), p. 539-541. • Wiedemann, E., "Über das al-Berunische Gefäss zur spezifischen Gewichtsbestimmung," *Verhandlungen der deutsche physikalische Gesellschaft*, **10** (1908), p. 339-343. • Wiedemann, E., "Verbreitung der Bestimmungen des spezifischen Gewichtes nach al-Beruni," *Beiträge 31, Sitzungsbericht Erlangen*, **45** (1914), p. 31-34.

on the principal of Archimedes, *Promotus Archimedes* [311] that contains a comparision that he made between the specific gravities of water and eleven other substances.

The Jesuit, Johannes Baptista Villalpandus of Cordova, Spain published his *Apparatus Urbis et Templi Hierosoymitani* (Rome, 1604), in which he exhibits a table of proportional weights of the seven metals together with some other substances. This table was reprinted several times.[312] In the collected works of Francis Bacon a table of specific gravities for 78 articles is given in his "Tabula Coitionis et Expansionis Materiæ". It was probably prepared about 1620, but was not published until after its inclusion in his works.[313] He preformed his measurements by comparing cubes of the measured substance against the weight of a cube made of pure gold of the same size.

Ghetaldus table was the basis for several other researchers. Edmund Gunter mentions the specific gravities of several metals, quoting from Ghetaldus in his postumonous *Description and Use of the Sector* (London, 1626), as does William Oughtred in the *Circles of Proportion* (1633), and D. Henrion his his *Usage du Compas de Proportion* (Paris, 1631).

Petitus' *L'Usage ou le Moyen de Pratiquer par une Regle toutes les Operations du Compas de Proportion. Augmentées des Tables de la Pesanteur et Grandeur des Metaux* (Paris, 16?????) gives the proportional densities of the seven metals.

Marinus Mersennus gives a table of specific gravities of the metals and some other substances in his *Cogitata Physico Mathematica* (Paris, 1644). He calculates pure gold to be 100, with other materials given in propotion to that number. For example, water is given the value 5 1/3.

In 1670, Smethwick, an early member of the Royal Society of London, communicated the weights of a cubic inch of several different substances that are indicated to have been measured by a Mr. Reynolds in the *Tower of London*. This seems to have been the same Reynolds that published *The Secrets of the Goldsmith's Art* (London, 1676), where in several tables show the price of gold and silver.[314]

The Philosophical Society at Oxford conducted experiments into the specific gravity of various materials using a hydrostatic balance, the results from which were placed in a table and published in the *Transactions of the Philosphical Society of London.*[315] A supplement to this table appeared in 1693.[316]

Robert Boyle appended a table of specific gravities of various bodies to his *Medicina Hydrostatica* (1st ed., London, 1690). He used a hydrostatic balance of his own design in his experiments. Also, in other of his works from time to time he makes reference to densities he has measured. Boyle suspected that stones contained metallic substances that could not be seen, even with the most powerful microscopes of the day. To prove his hypothesis, he turned to determining the specific gravity of various minerals. Boyle choose a colorless rock crystal as his normal precious stone, to which he would compare the density of all other stones. He determined the specific gravity by weighing a specimen both in air and in water (=1.0), and found that rock crystal, had a density 2 2/3 times that of water. This result also drew Boyle's attention to the long held theory that rock crystal was actually some form of very hard ice. Boyle believed that he shows conclusively from his density measurement that because rock crystal, which is harder than ice, is also much more dense (rock crystal sinks in water while true ice floats) that rock crystal was not some form of ice. This conclusion also lead Boyle

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[312] Joh. Henr. Alstedius., *Encyclopædia Universa*. Herborn, 1630. 2 vols.; Henry Van Etten., *Mathematical Recreations*. London, ????, which was itself copied into other works.

[313] Francis Bacon., *Historia Densi*. London, 1741, **2**, p. 69.

[314] Davies, p. 424-425.

[315] Musgrave, "???," *Transactions of the Philosphical Society of London*, no. 169 (1684).

[316] John Caswell., "???," *Transactions of the Philosphical Society of London*, no. 199 (1693).

to the idea that the harder precious stones contained metallic particles that might also act as a coloring agent to the gem. He found that garnets from America were four times heavier then water. Thereby he precieved that colored precious stones which did not exceed the density of rock crystal, were nonetheless colored from a metallic substance. Boyle then observed that ice made from mineral water were not preceptibly heavier than ordinary water. Experimenting with opaque stones he found similar differences in specific weight, and calculated the density of jet at 1.22, white marble to be 2.7, magnet at 4.6, hematite at 5.7, etc. Atypical of his age, Boyle did not entangle himself in the medical virtues of stones; however, he did say, that of the diamonds, rubies, and sapphires, that were carried in rings, never has any medical effect been noted, and that many downright unbelievable stories have been told.[317]

In 1699, Homberg of the Royal Academy of Sciences in Paris read a memoir that showed that bodies expand when hot and contract when cold. Thereafter, it was quickly realized that the specific gravities of the same body could change depending on whether the measurement was made in summer or winter. Homberg actually showed that this change did occur by experimenting on several fluids and using an insturment he called an Aræometer, which consisted of a large vial with a long and slender stem from which he could make exact measurements. He filled the vial with the fluids he wanted to measure and showed that depending on the temperature the density of the liquid changed. He appended a short table to his memoire published that year.[318]

Appended at the end of John Freind's *Prælectiones Chymicæ* (London, 1709) are a series of tables listing the specific gravities of both solid and fluid bodies, made entirely from the results of his own experimentation. Davies (1748) considers his trials poorly conducted with many errors.

The famous English geologist John Woodward made a great number of experiments on the specific gravities of minerals and other solid bodies, but that remained unpublished at his death in 1728. Only occassional mentions of densities are made in his *An Attempt Towards a Natural History of the Fossils of England* (London, 1729).

The Dutch physicist Peter van Musschenbroek included a large table of specific gravities of solids and liquids in his *Elementa Physicæ* (Leyden, 1734). It was somewhat expanded in the French translation of the work, *Essai de Physique* (Leyden, 1739). The data for the tables was collected from previous works, without naming the authors cited.

A Fellow of the Royal Society, John Ellicott had an amazing opportunity in 1745 to weigh 14 large diamonds. Using the best assay scales available, accurate to 1/200th of a grain, he took the specific gravities of those stones. Four of them came from Brazil, while the remaing ten were recovered from the East Indies. Ellicott sent his results to the Royal Society, where they were published in the *Transactions*.[319] Due to the large size of the stones, and the quality of his equipment, it was all the easier to calculate their densities at 3.51 as compared to the modern 3.511.

Richard Davies in his "Tables of Specific Gravities" combines the results of about two dozen authors into a short series of tables together with a valuable history of experiments on density prior to his paper.[320]

Abraham Gottlob Werner in his *Von den äusserlichen Kennzeichen der Fossilien* recommends an accurate determination of the density when it can be obtained, but otherwise generally divides the determination of specific gravity into five divisions: 1. *Supernatant*, or the mineral floats on water, 2. Light, 3. Not remarkably heavy, 4. Heavy, and 5. Very heavy. This gross determination he explains is learned from long experience of weighing specimens by hand.

The accomplishments of Richard Kir-

[317] Robert Boyle., *Essay about the Origine and Virtues of Gems*, London, 1672, p. 80-84.

[318] Homberg., *Memoires de Academie des Sciences*, 1699.

[319] John Ellicott., "???," *Transactions of the Royal Society*, 1745, no. 476.

[320] Richard Davies., "Tables of specific gravities", *Philosophical Transactions of the Royal Society of London*, **45** (1748), p. 416-489.

wan in eighteenth mineralogy were important. In his important *Elements of Mineralogy*, he concentrated on the physical and chemical properties of a mineral to determine its placement in his classification. Although he utilized all properties available, he did not really use crystal form saying: "The variation in the forms of crystallized bodies I will not specifically examine, especially since I regard them as very little details."[321] Specific gravity Kirwan sought to determine exactly, believing that it was one of the most accurate properties to distinguish one mineral from another. For reference, he utilized the information published by Mathurin Jacques Brisson in his important *Pesanteur Spécifique des Corps* (Paris, 1787), which was considered complete and superior to all other specific gravity studies. Kirwan in his examination used a hydrometer of the form invented by William Nicholson (see §14.3.2).

René Just Haüy had previously reported on the usefulness of the instrument in determining the density of minerals, even publishing a report on the instrument.[322] He also used an areometer based on Nicholson's design in his evaluation of specfic gravities that were incorporated into his mineralogical studies and published in his *Traité de Minéralogie* (1801).

François Sulpice Beudant used a similar device in determing his densities, which he published in his *Traité Élémentaire De Minéralogie* (1824). Beudant also published a study on the measurement of specific gravity.[323] He examines the fluctuations in the measurements, especially when examining varieties of mineral species, and attributes the difference to minute cavities in the specimen. He suggests grinding the mineral to a powder before measuring its density to eliminate air cavities.

Other mineralogists of the nineteenth century also focused attention on specific gravity determination.

Wilhelm Haidinger (1825),[324]

In earlier times used of Hessel for the pumice stone suggested pulverizing the material before making its specific gravity determination. are (*Leonhard's Taschenbuch für Mineralogie*, 1825, II, p. 344), supplies in some cases completely surprising, and anyhow such results, the very close normal specific Weight of the substance to represent would be allowed to do.

Robert Hare (1826),[325]

Although after Osann and Girard that influence of the capillaritiit small fluctuations causes, depending on a larger or smaller quantity of the cut up mineral is weighed.[326]

Between 1841 and 1845 Hermann Kopp [??-??] apparently studied the specific gravity of bodies with particular enthusiasm. He authored papers on the subject of specific gravity,[327] as well as a book.[328]

T. Scheerer (1846),[329]

1848: One compares also Gustav Rose's paper over the errors with that determination of the specific weight of very finely ground bodies from which he gives itself that those much purify chemical precipitation, not

[321] Richard Kirwan., *Elements of Mineralogy*. London, 1794, **1**, p. 38-42.

[322] R.J. Haüy., "Exposition abrégée de la théorie sur la structure des cristaux," *Journal d'Histoire Naturelle*, **1** (1792), p. 159 ff..; *ibid.*, "Exposition abrégée de la théorie sur la structure des cristaux," *Journal de physique*, 1793, p. 1.

[323] F.S. Beudant., "Notice sur la pesanteur spécifique des corps, considérée comme caractère minéralogique," *Annales de Chimie et de Physique*, **38**, p. 398-411.; German translation, "Ueber das specifische Gewicht der Körper, als Kennzeichen der Mineralien," *Annalen der Physik (Poggendorff)*, **14** (1828), p. 474-484.

[324] Wilhelm Haidinger., "Account of the specific gravity of several minerals," *Edinburgh Journal of Science*, **2** (1825), p. 67-74.

[325] Robert Hare., "On specific gravity," *American Journal of Science*, **11** (1826), p. 121-132.; *ibid.*, "Opinion on hydrometers," *American Journal of Science*, **11** (1826), p. 115-119.

[326] Osann and Girard., "???," *Archiv für Mineralogie, Geognosie, Bergbau und Hüttenkunde (Kastner)*, **1** (1829), p. 58 ff.

[327] H. Kopp., "Ueber die Verhaltnisse zwischen Atomgewicht und specifischen Gewicht bei festen und flüssigen Körpern," *Liebig, Annal.*, **40** (1841), p. 173-182.; *ibid.*, "Uebersicht der Resultate einiger Arbeiten, welche Regelmäßigkeiten in den specifische Gewichten und den Siedepuncten chemischer Verbindungen behandeln," *Erdm. Journ. Prak. Chem.*, **34** (1845), p. 1-36.

[328] Hermann Kopp., Über das spezifsche Gewicht der chemischen Verbindungen. Frankfurt am Mainz, 1841.

[329] T. Scheerer., "Ueber die Bestimmung des specifisen Gewichtes von Mineralien," *Poggendorff's Annalen*, **67** (1846), 120.; *idem.*, *Journal. pr. Ch.*, **24** (1846), 139.

however by mechanical cutting up represented powders show a higher specifisches weight, than such the concerned Comes to bodies in the crystallization. Rose finds however, that the specific gravity of the powdered mineral is significantly different than the unground mineral.[330]

1852: Gustav Adolf Kenngott[331]

1856: Kohlrauach, *Praktische Regeln zur genaueren Bestimmung des spezifischen Gewichtes* (Marburg, 1856).

1856: Uses one however by Miller in the years 1856 indicated improvement of this apparatus, so giebt giebt-er more exact results; the Modification of the same suggested by Regnault is still more appropriate.

1856: Also Jenzsch describes in an apparatus and a method for more exact determination the specific weight.[332]

1858: Hugo Schiff [1834-????] gave occasionally remarks over the influence of mechanical cutting up of the mass on the large one the specific weight, and it found by attempts that the latter fills out usually more highly, if the mass is finely ground. He believes the cause of this feature in one, by the attraction of mass caused compression of the water at the surface to be able to find the weighed body. He described his own method for determining specific gravity.[333]

Specific gravity of powdered substances was investigated at the end of the 18th century. Leslie suggested determing the specific gravity by measuring the powdered substance. But actually Say had already described the procedure and invented apparatus to make the measurement.[334] In the paper he described apparatus and gives a long exercise, but his accuracy is never great. That is why Karsten could not recommend the procedure.[335]

1859: Axel Gadolin indicated a simple method, which substantially on application one dares with divided daring bar been based, on which the sample which can be balanced and the weight to be shifted can[336]

1859: Good remarks over the more exact determination of the specific weight gave also Schröder in the introduction to his paper:[337]

1859: Gottfried Wilhelm Osann [1797-1866] gives a paper on a new method to determine the weight.[338]

[ADD all before 1864: Raimondi, Eckfeld and Dubois, A. Meyer]

1863: A similar procedure has Tschermak into that *Sitzungsberichten der Kais. Akademie der Wissenschaften zu Wien*, 1863, suggested.[339]

1866: Methods and apparatuses for the exact determination of specific weights is indicated by Scheerer[340] and Marchand.[341]

In 1868, Websky published a system of mineral classification based principally on the specific gravity of the mineral species.[342]

[330] Gustav Rose, "Ueber die Fehler, welche in der Bestimmung des specifischen Gewichtes der Körper entstehen, wenn man dieselben im Zustande der feinsten Vertheilung wägt," *Annalen der Physik (Poggendorff)*, **73** (1848), p. 403 & **75** (1848), p. 403.

[331] G.A. Kenngott., "Verhältniss zwischen dem Atomgewichte, der Härte und dem specifischen Gewichte isomorpher Minerale," *Wien, Geol. Jahrb.*, **3** (1852), Heft 4, p. 104-116.

[332] Jenzsch., "Ueber die Bestimung der specifischen Gewichte," *Annalen der Physik (Poggendorff)*, **99** (1856), p. 151 ff.

[333] H. Schiff, "Über die Bestimmung des specifisches Gewicht," *Annalen der Chemie und Pharmacie.*, **108** (1858), p. 29.

[334] Say., "???," Ann. de Chimie (**33**, 1797, p. 1

[335] Karsten., "???," *Schweigger's Neuem Jahrbuch*, **5**, 1832, p. 408 f.

[336] A. Gadolin., "Eine einfache Methode zur Bestimmung des Specifischen Gewichte der Mineralien," *Annalen der Physik (Poggendorff)*, **106**, 1859, p. 215 ff.; See also, *Sitzungsber. d. W. Ak.*, **47**, p. ??-??.

[337] Schröder., "Neuere Beitrge zur Volumentheorie" *Annalen der Physik (Poggendorff)*, **106**, 1859. p. 226 ff.; *ibid.*, "Die Volumconstitution einiger Mineralien," *Jahrbuch für Mineralogie*, (1873), 561 & 932; *ibid.*, (1874), 399, etc.

[338] G.W. Osann., "Über Bestimmungen der specifisches Gewicht fester Körper," *Annalen der Physik (Poggendorff)*, **73**, 1848, p. ??-??.; *ibid.*, "Neue Bestimmungsweise der specifische Gewicht fester Körper," *Annalen der Physik (Poggendorff)*, **106**, 1859, p. 334 ff.

[339] Gustav von Tschermak, "???," *Sitzungsberichten der Kais. Akademie der Wissenschaften zu Wien*, **47** (1863), 292.

[340] Scheerer., "???," *Annalen der Physik (Poggendorff)*, **67** (1866), p. 120.

[341] Marchand., "???," *Journal for prakt. Chemie*, **24**, p. 139.

[342] ?? Websky, *Die Mineralien nach den für das specifische Gewicht derselben angenommenen und gefunden Werthen.* Breslau, 1868. 170 p.

It never found wide acceptance, however, and today remains a curious book in the mineralogical literature.

1879: V. Thoulet[343]

1880: Pisani[344]

1881: Thoulet[345]

1881: C. Klein[346]

In his 1881 dissertation, Viktor Goldschmidt mentions his procedure for obtaining the specific gravity.[347]

In 1882 P. Gisevius published a dissertation on the subject of specific gravity and its determination in minerals.[348] In 1885, Gisevius also published a further paper on the subject.[349]

Victor Goldschmidt (1886). [350]

1886-1888: R. Brauns, Über die Verwendbarkeit des Methylenjodids etc. N. Jahrb. f. Min. 1886, II, 72; 1888, I, 263.

Dölter, Sitzungsber. d. W. Ak., Bd. 85, S. 47.

In the twentieth century other mineralogists studied mineral densities:

Earl Berkeley (1907),[351]

H.E. Merwin (1911),[352]

Friedrich Becke (1911),[353]

Maurice Billy (1913),[354]

Edgar B. Wastell (1914).[355]

A valuable list of the specific gravities of minerals that gives minimum and maximum values was given by Leonhard J. Spencer in 1927.[356]

## 5.3 Cleavage[357]

Of all the physical characters of a crystal, the curious property known as "cleavage" is one of the most easily observed. When struck with a hammer or pressed with the blade of a knife, many crystals separate along molecular planes. For example, mica and gypsum may be easily split into large sheets of any desired thickness. Diamond which crystallizes in the form of an octahedron may also be split or "cleaved," parallel to each of its eight faces, thus forming a smaller octahedron. These cleavage planes, which in diamond are very pronounced, are often perfectly smooth and have a brilliance comparable to the natural crystal faces. Noticed by the ancient Indian jewelers cleavage was used effectively to help shape natural diamond crystals into gemstones.

Cleavage is also pronounced in many other minerals and was probably also known in

[343] V. Thoulet., "???," *Bull, soc. min.*, **2** (1878), p. 189.

[344] F. Pisani., "Neues Instrument für Bestimmungen der specifisches Gewicht," *Zeitschrift für Krystallographie*, **3** (1880), p. 105.

[345] Thoulet., "Bestimmung der specifisches Gewichte kleiner Mineralfragmenten," *Zeitschrift für Krystallographie*, **4** (1881), p. 421.

[346] Klein., "???," *Bull, soc. min.*, **4** (1881), p. 149.

[347] V. Goldschmidt., *Verwendbarkeit einer Kaliumquecksilber-jodidlösung bei mineral. Untersuchungen.* Dissertation, Heidelberg 1881. Abstracted in, *Jahrbuch für Mineralogie*, 1881, Beilageband I, p. 179 ff.

[348] P. Gisevius., *Beiträge nur Methode der Bestimmung des specifisches Gewichts von Mineralien und der mechanischen Trennung von Mineralgemengen.* Inaug.-Dissertion, Bonn, 1882. 81 p. [Abstracted in *Annalen der Physik*, **7** (1883), no. 5, p. 325-326, and in *Fresenius' Journal of Analytical Chemistry*, **23** (1884), no. 1, p. 51.

[349] P. Gisevius., "Methode zur Bestimmung des specifisches Gewicht," *Zeitschrift für Krystallographie*, **8** (1885), p. 420.

[350] Victor Goldschmidt., "Ueber das specifische Gewicht von Mineralien," *Verhandlungen Geologischen Reichsanstalt* (Maybe *Verhandlungen der Geologischen Bundesanstalt*, Wien, 1886, p. 439-445.

[351] Earl Berkeley., "The more exact determination of the densities of crystals," *Journal of the Chemical Society*, London, **91** (1907), p. 56-62.

[352] H.E. Merwin., "A method of determining the density of minerals by means of Rohrbach's solution having a standard refractive index," *American Journal of Science*, Series 4, **32** (1911), p. 425-428.

[353] Friedrich Becke., "Das spezifisches Gewichte der Tiefengesteine," *Min. Petr. Mitt.*, Neue Folge, **30** (1911), p. 475-478.

[354] Maurice Billy., "Méthode simple pour détermination la densité des poudres minérales," *C.R. Acad. Sci.*, **156** (1913), p. 1065-1067.

[355] Edgar B. Wastell., "Specific gravity differences," *Chemical News London*, **109** (1914), p. 58.

[356] Leonhard J. Spencer., "Specific gravities of minerals: an index of some recent determinations," *Mineralogical Magazine*, **21** (1927), p. 361-365.

[357] Further historical information may be found in: A. Johnsen., "Die Struktureigenschaften der Kristalle," *Fortschritte der Mineralogie, Kristallographie und Petrographie*, **3** (1913), p. 93-140. [In this discussion of structural properties of crystals, the section on cleavage begins with a short historical introduction.] • M.D. Shappell., "Cleavage of ionic minerals," *American Mineralogist*, **21** (1936), no. 2, p. 75-102. [Contains an interesting history to the subject in the late 19th and first decades of the 20th century.] • H. Tertsch., "Zur Frage der Spaltbarkeit," *Tschermaks mineralogische und petrographische Mitteilungen*, **??** (1986), p. 13-??.

Europe during the Middle Ages, if not earlier. Galena, a common ore of lead in central Europe, can be easily split parallel to all its three pairs of faces and may thus be subdivided into small cleavage cubes and undoubtedly would have been easily identified by the Middle Age miners because of this property.

Starting in the 17th century, cleavage angles were measured by researchers, and although they may have suspected that the property occurred because of some internal structure of the crystal, aparently all they did was record their observations. Robert Boyle compared the cleavage of diamond with that of rock salt (halite),[358] and Domenico Guglielmini recognized that the cleavage angle of rock salt was always constant.[359]

Other minerals which showed a good cleavage were soon discovered. Antonio van Leeuwenhoek found that the interfacial angle of the gypsum cleavage on face $(\bar{1}11)$ against (100) or (010) was constant at 68° (compared to the modern 69° 9 1/2').[360] The common mineral, calcite, which in its crystallized form can easily be split along molecular planes, quickly became a favorite material for cleavage investigations. Erasmus Bartholin was the first to show that the interfacial angle of its fragments was always constant. In 1669, he measured the angle at 103° 40'.[361] In 1690, Christian Huygens measured the angle at 105°,[362] which was followed in 1710 by Gabriel de la Hire's measurement of 105°.[363] A century later, with better instruments, including the reflecting goniometer invented in 1809, the angle was more exactly measured by Étienne Louis Malus in 1810 at 105° 5',[364] by William Wollaston in 1812 at 105° 5',[365] and by Adolph Theodor Kupffer in 1825 at 105° 4.5'.[366]

In the 18th century during a lengthy discussion of fracture in minerals, Abraham Gottlob Werner also includes a section "On the Form of Fragments" that describes the cleavage property. He notes that when broken some minerals separate into one of six different geometric shapes: cubic, rhomboidal, pyramidal, cuneiform, scaly, and tabular.[367] He also includes "irregular" as a seventh option, which serves as a catch all for those minerals that show no distinct cleavage. Although Werner observes that the broken fragments have a geometrical shape to them, in no way does he relate this to a mineral's crystal form. In his mind it is simply a mineral diagnostic, and from Werner's time forward, cleavage was routinely included in the description of those minerals that exhibited the property.

Cleavage was one of the few properties available in the 18th century that reflected information about the atomic structure of a crystal. For a long time it was implicitly recognized that an interrelationship existed between the geometrical arrangement of the molecules of a mineral and the cleavage it exhibits. Theories of crystal structure therefore led to attempts to explain cleavage while similtaneously research on cleavage gave an understanding of crystal structure. Nevertheless in spite of attempts to resolve the problem, the phenomena of cleavage continued as one of great difficulty to fully understand.

Guglielmini speculated that the cleave fragments of calcite represented a primitive polyhedra from which the crystals were built. Decades later, after his own experimentation, Christian F. Westfeld concluded that crystals of calcite were formed from a

[358] R. Boyle., *Specimen de Gemmarum Origine*. Hamburgi, 1683.

[359] D. Guglielmini., *Opera Omnia*. Genevae, 1719, p. 83.

[360] A. van Leeuwenhoek., *Arcana Naturae Detecta*. Delphis Batav., 1695, p. 124.

[361] E. Bartholin., *Experimenta Crystalli Islandici Disdiaclastici*. Hafniae, 1669.

[362] C. Huygens., *Traité de la Lumière*. Leiden, 1690.

[363] G. de la Hire., "Observations sur une espèce de talc qu'on trouve communément proche de Paris au-dessus des bancs de pierre de plâtre," *Mémoires de l'Académie Royale des Sciences*, 1710, p. 341-352.

[364] É.L. Malus., *Théorie de la double Reflexion*. Paris, 1810, p. 98.

[365] W. Wollaston., "On the primitive crystals of carbonate of lime, bitter-spar and iron-spar," *Philosophical Transactions*, 1812, p. 159.

[366] A.T. Kupffer., *Preisschrift über genaue Messung der Winkel*. Berlin, 1825, p. 65.

[367] A.G. Werner., *Von den äusserlichen Kennzeichen der Fossilien*. Leipzig, 1774, p. 227-230.

rhombohedral shaped molecule.[368] Johann G. Gahn who was an expert in blowpipe analysis, worked in the 1760's in the laboratory of Torbern Olaf Bergman. Together, they investigated many minerals and crystals, and sometime during that period they found that when crystals of Iceland spar (calcite) were split along their cleavage planes, the resulting fragments could be reduced to smaller and smaller rhombohedrons. In 1773, Bergman published his findings including observations about cleavage.[369] According to Bergman, calcite was built from a rhombohedron shaped nucleus whose surfaces had angles of 101 1/2° and 78 1/2°. These could easily be discovered by measuring the cleavage fragments of the calcite which Bergman said reflected the shape of nucleus. He goes on to explain how the hexagonal crystal of calcite can be constructed from these smaller rhombohedrons.[370]

Richard Kirwan suggested that a relation exists between magnetism and cohesion in 1797.[371] He attributed crystallization and magnetism to the same physical cause, and the parting along cleavage planes as a breaking of a bond similar to a magnetic connection.

In 1784, the property acquired a new importance with the researches of the Abbé René Just Haüy, who was the first to make the general observation that all crystals of the same substance possess the same cleavage. He was led by this observation to develop a mathematical theory of crystal structure that explained all the known facts, and for the first time set mineralogical science as a whole on a mathematical foundation.

"The fundamental idea of my whole theory was suggested to me by an observation which I made upon calcareous spar in six-sided prisms terminated by two hexagonal faces. I had noticed that a crystal of this variety, having been detached by chance from a group, was broken obliquely across in such a way that the fracture presented a clean surface, having the luster which may be recognized as Nature's polish. I then endeavored to obtain from the same prism sections in other directions, and after several attempts succeeded in obtaining from each side of the prism three oblique sections; by new sections parallel to the first I removed from the center of the prism a rhomboid precisely similar to Iceland spar. Struck with this observation, I took other calcareous spars, ... and I found in them the same rhomboidal kernel which had been yielded by the prism mentioned above. Similar trials made upon crystals of several different kinds soft enough to be smoothly divided gave me kernels which had other shapes, but of which each was invariable in the same kind of crystal." [372]

Until that time, cleavage was used only as a deterministic property to distinguish one mineral species from another. However, Haüy for the first time explicitly stated that cleavage was intertwined with the molecular structure of crystals, and theoretically, its study would allow the mineralogist to discover ideas about the arrangement of atoms within the crystal lattice.[373] Around this central concept Haüy developed a comprehensive view of mineralogical science, which was ultimately published in the important and influential *Traité de Minéralogie* (1801).

Cleavage was described by Friedrich Mohs in his *Grundriss der Mineralogie*. He believed that the property was a remarkable phenomenon of inorganic nature, intimately related to the mineral species that exhibited the property. One infers from his discussion that he believed cleavage integral to the crystal and was, therefore, a property that would continue to be exhibited even if the crystal was microscopic in size.[374]

François Sulpice Beudant included a description of cleavage in the first edition of his own *Traité de Minéralogie* (1824), and notes its presence in those minerals that display the

[368] C.F. Westfeld., *Mineralogische Abhandlungen*. Göttingen, 1767, p. 50.

[369] T. Bergman., "Variae crystallorum formae a spata ortae," *Nova Acta Regiae Societatis Scientiarum Upsaliensis*, **1** (1773), p. 150-155.

[370] R. Hooykaas., "Torbern Bergman's crystal theory," *Lychnos*, **1952**, p. 21-54. • J.A. Schufle., *Torbern Bergman. A man before his time*. Lawrence, Kansas, Coronado Press, 1985, p. 328.

[371] R. Kirwan., "Thoughts on Magnetism," *Transactions of the Royal Irish Academy*, **7** (1797), p. 177.

[372] R.J. Haüy., *Essai d'une théorie sur la structure des crystaux*. Paris, 1784, p. 10.

[373] R.J. Haüy., *Essai d'une théorie sur la structure des crystaux*. Paris, 1784, p. 75.

[374] F. Mohs., *Grundriss der Mineralogie*. Berlin, 1822, **1**, p. 269, 277.

property.[375] He notes that in crystallized minerals that the cleavage displayed by the interior structure can be totally different than the external form, and that the property is most prominent in calcite.

In 1823 Antoine César Becquerel studied the electrical current created by some crystals when they are pressed or cleaved.[376] Similar studies later in the century lead to the recognition of piezoelectricity property (§5.7.3).

In 1835, Moritz Ludwig Frankenheim theorized that during the formation of a crystal, interruptions in the crystallization process could create a layering effect in the molecular structure and, thereby, contribute to cleavage planes.[377]

Beginning in 1848, Auguste Bravais published a series of papers in which he first treated the variety of geometric shapes formed by points distributed regularly in space and then applied these ideas to crystals, with the points representing the centers of gravity of the chemical molecules or as points of atomic force.[378] Under this approach, Bravais developed a method to explain the cleavage and external symmetry of crystals as a result of the reticular density of the molecules inside the crystal. He theorized that cleavage occurred most easily parallel to the plan of the greatest point density. Using this model he calculated relative values for potential planes where cleavage occurred and ranked them from strongest to weakest. Just how the atoms or molecules were arranged within the unit cells formed by the space lattice stayed, however, a matter of conjecture. Because it was known that the symmetry of the crystal was related to the pattern of the internal structure, it was not a stretch to believe that cleavage also developed from the same structural elements.

When the great German crystallographer Leonard Sohncke was developing his own theory of spacial points arranged in crystallographic patterns, he used his observations of cleavage to support his work. An early paper described his investigations into the cohaesion of crystals of rock salt (halite) along different directions.[379] While in his later work he thought cleavage depended upon the breaking of atomic bonds tangential to where the cohesion was greatest.[380] The assumption being made that such layers are more strongly held together the restult is greater tangentail cohesion inside the layer while the interlayer connections are weaker, thus giving rise to cleavage. Judging if Sohncke's application was correct required knowledge of the crystal structure. Only in 1914 were Peter Paul Ewald and Wilhelm Friedrich able to conclude that this model was correct after examing the structure of pyrite using the newly invented X-ray method.[381] Johannes Stark took the model further by considering crystals in which the atoms can be considered as ions. He considered cleavage to be the repulsion of similar ions located on adjacent planes as they approached each other during the shearing process.[382]

In some cases cleavage which is not ordinarily observed in a mineral may be developed by a sharp blow or by sudden change of temperature. Quartz is, for example, usually free from obvious cleavage but a quartz crystal

[375] F.S. Beudant., *Traité de Minéralogie*. Paris, 1824, p. 35-39.

[376] A.C. Becquerel., "Sur le développement de l'électricité par la pression," *Annals de Chimie*, **22** (1823), p. 5-34.; German translation, "Von einigen durch Drücken und Spalten der Krystalle hervorgebrachten elektrischen Erscheinungen," *Annalen der Physik* (Poggendorff), **12** (1828), p. 147-152.

[377] M.L. Frankenheim., *Cohaesion*. Breslau, 1835, p. 325.

[378] A. Bravais., "Les systèmes formés par des points distribués régulièrement sur un plan ou dans l'espace," *Journal de l'École Polytechnique*, **19** (1850), p. 1-128. [The paper was presented to the Academy of Sciences on 11 December 1848. There is an English translation of this work by Amos J. Shaler, *On the Systems Formed by Points Regularly Distributed on a Plane or in Space* published by the Crystallographic Society of America, 1949.]; *ibid.*, "Etudes cristailographiques," *Journal de l'Ecole Polytechnique*, **20** (1851), p. 101-276. The paper was presented to the Academy of Sciences on 26 February and 6 August 1849.]

[379] L. Sohncke., "Ueber die Cohäsion des Steinsalzes in krystallographisch verschiedenen Richtungen," *Annalen der Physik (Poggendorff)*, **213** (1869), p. 177-200.

[380] L. Sohncke., "Ueber Spaltungsflächen und naturliche Kristallflächen," *Zeitschrift für Kristallographie*, **13** (1887), p. 214-235.

[381] P.P. Ewald and W. Friedrich., "Röntgenaufnahmen von kubischen Kristallen, insbesondere Pyrit," *Annalen der Physik*, **4** (1914), p. 1183-1184.

[382] J. Stark., "Neuere Ansichten über die zwischen- und innermolekulare Bindung in Kristallen," *Jahrbuch der Rad. und Elek.*, **12** (1915), p. 279-296.

heated and plunged into cold water often separates along planes to form both the positive (+) and negative (–) rhombohedrons and to the prism as well.

In 1886 Johannes Georg Lehmann discusses cleavage and parting planes in various minerals, including quartz,[383] while John Wesley Judd examined the property in quartz specifically.[384] Quartz cleavage was also studed in 1890 by François Ernest Mallard.[385]

Other minerals were investigated as well. Alexander Sadebeck treats the property in an 1876 paper that covers cleavage shapes, the condition of the cleave surface, relationship between cleavage and crystal form, and glide planes for a number of species.[386] Samuel Penfield describes the perfect of cleavage of topaz in his study of the mineral.[387] The two perfect cleavages of calcite and how to obtain them were studied by Georges Friedel in 1902.[388]

The Italian crystallographer Carlo Viola investigated aspects of cleavage in a variety of minerals,[389] while Hermann Tertsch concentrated his investigation to cleavage observed in minerals that crystallized in the trigonal and hexagonal system.[390] Many crystals of this type were exceptional because they did not strictly follow Bravais' theory of structure and cleavage, and Tertsch records those exceptions he has encountered.

William Barlow considered the problem of the internal structure of crystals from the point of view of a physical model, where the atoms in a crystal behaved like small spheres that packed themselves into as tight a volume as possible.[391] After examining the issues of packing identical sized spheres or atoms, he attempted to model the structure that was created by packing of spheres of different sizes, which were probably necessary for the arrangement of atoms in simple binary chemical compounds. He accepted that cleavage was a condition that broke the atomic bonds between particles and used experimental observations of the property to strenghten his theoretical model.

It was becoming clear that a great deal of information about the internal arrangement of chemcial molecules could be inferred from how cleavage developed in crystals. In 1904 a few years before X-ray analysis was invented Jacob Beckenkamp wrote on cleavage and molecular structure.[392] Years later, after X-ray analysis was fully established, he retuned to the subject when he presented his theory of atomic structure and its relationship to cleavage in crystals.[393] Now Beckenkamp's treatment is a combination of the theories of Sohncke and Stark.

It was in 1912 with the introduction of X-ray analysis that the most profound impact on understanding the arrangement of atoms in minerals. Conversely, the overlay of cleavage planes on crystal structures began to be studied by mineralogists. Hermann Tertsch looked at the question of cleavage and matched the property to geometric planes contained in the

[383] J.G. Lehmann., "Contractionsrisse an Krystallen," *Zeitschrift für Kristallographie*, **11** (1886), p. 608-613.; Abstracted in: *Naturwissenschaftliche Rundschau*, **2** (1886), no. 11, p. 87.

[384] J.W. Judd., "On the development of a lamellar structure in quartz crystals by mechanical means," *Mineralogical Magazine*, **8** (1888), p. 1-9.

[385] F.E. Mallard., "Sur les clivages du quartz," *Bulletin Societe Mineralogie France*, **13** (1890), p. 61-62.

[386] A. Sadebeck., "Über die Teilbarkeit der Krystalle," *Schriften des Naturwissenschaftlichen Vereins für Schleswig-Holstein* (Berlin), **1876**, p. 29-47.

[387] S. Penfield., "Zusammensetzungen der Topas. Beziehung zu physikalische Eigenschaften," *Zeitschrift für Kristallographie*, **23** (1894), p. 262-271.

[388] G. Friedel., "Sur deux clivages de la calcite," *Bulletin de la Société Française de Minéralogie*, **25** (1902), p. 113-115. [See also J. Donnay et al., "Various modes of attack in crystallographic investigations ," *American Mineralogist*, **19** (1934), p. 437-458.]

[389] C. Viola., "Beitrag zur Lehre von der Spaltbarkeit der Krystalle," *Neues Jahrbuch für Mineralogie*, **1902**, I, p. 9-23.

[390] H. Tertsch., "Spaltbarkeit und Structur im trigonalen und hexagonalen Systeme," *Zeitschrift für Kristallographie*, **47** (1909), p. 56-74.

[391] W. Barlow., "A Mechanical Cause of Homogeneity of Structure and Symmetry," *Proceedings of the Royal Dublin Society*, new series, **8** (1897), 527-690.

[392] J. Beckenkamp., "Beziehg. der Spaltbarkeit zur Molekularstruktur," *Zeitschrift für Kristallographie*, **39** (1904), 2 p.

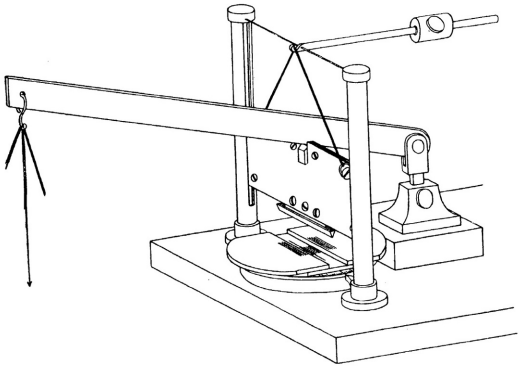
[393] J. Beckenkamp., "Atomanordnung und Spaltbarkeit," *Zeitschrift für Kristallographie*, **58** (1923), p. 7-39.

Bravaisian lattice strucuture.[394] Maurice L. Huggins in 1923 matched the observed cleavage planes of several minerals to the atomic structure derived from their X-ray analysis.[395] Of the several minerals examined there were included diamond and sphalerite. He concluded that the new crystal surfaces that resulted from cleavage must be electrically neutral, that weak atomic bonds would rupture in preference to strong bonds, and that when all bonds were equally strong, the plane of cleavage would break the fewest bonds per unit area. In a comprehensive study published in 1936, M.D. Shappell explored the reasons that cleavage occur in ionic minerals.[396]

Through out most of the 19th century, cleavage was only included in the description of a mineral if the species in question exhibited the property. However, in 1892, with the publication of the sixth edition of *Dana's System of Mineralogy* by Edward Salisbury Dana, cleavage became a standard diagnostic. Every mineral Dana listed now included a description of its cleavage, even if the species did not exhibit one. So influential was the sixth edition that every handbook after it that gave any meaningful description of minerals also includes cleavage as a physical property for each of the species.[397]

### Testing Apparatus

Suprisingly, no attempts were undertaken to create a standard measure of a crystals ability to cleave until the 20th century. Through out the history of mineralogy, the property was given in the description of minerals as perfect, distinct, non-distinct, nonexistant, etc. It was not until Hermann Tertsch in the 1930's that any attempt was made to develop a standard method to test the cohesion of crystals.[398] Using a guillotine-like machine that could apply a measured pressure along a thin line of a mineral plate placed beneath, Tertsch tested the cleavage of sample. With this device the same conditions could be reproduced on a variety of minerals and determine the exact amount of pressure required to cause cleavage. However, few other researchers followed in his footsteps,[399] and the property generally remains a measurement of relative values.



Tertsch's Cleavage Tester (1930)

## 5.4 Luminescence[400]

[394] H. Tertsch., "Zur Frage der Spaltbarkeit," *Tschermaks mineralogische und petrographische Mitteilungen*, **35** (1921), p. 13-30.; *ibid.*, "Bemerkungen zur Spaltbarkeit," *Zeitschrift für Krystallographie*, **65** (1927), p. 712-718.

[395] M.L. Huggins., "Crystal cleavage and crystal structure," *American Journal of Science*, 5th series, **5** (1923), p. 303-313.

[396] M.D. Shappell., "Cleavage of ionic minerals," *American Mineralogist*, **21** (1936), no. 2, p. 75-102. [Contains an interesting history to the subject in the late 19th and first decades of the 20th century.]

[397] A recent example is contained in John W. Anthony, Richard A. Bideaux, et al., *Handbook of Mineralogy*. Tucson, Arizona, 1990-2003. 5 vols.

[398] H. Tertsch., "Einfache Kohäsionsversuche I," *Zeitschrift für Kristallographie*, **74** (1930), p. 476-500.; *ibid.*, "Einfache Kohäsionsversuche II," *Zeitschrift für Kristallographie*, **78** (1931), p. 53-75.; *ibid.*, "Einfache Kohäsionsversuche III," *Zeitschrift für Kristallographie*, **81** (1932), p. 264-274.

[399] G. Frenzel., "Cleavage in pyrite," *American Minerlogist*, **52** (1967), p. 994-1005. [Includes a picture of a machine similar to Tertsch's to make his measurments of cleavage.]

[400] Further historical information may be found in: M.C. Goldberg and E.R. Weiner., "The science of luminescence," (pp. 1-22) in: M.C. Goldberg and E.R. Weiner., *Luminescence applications in biological, chemical, environmental, and hydrological sciences*. Denver, ACS Symposium Series, 1989. [Gives a short history of luminescence.] • E. Harvey., *A history of luminescence, from earliest times until 1900*. Philadelphia, American Philosophical Society, 1957. xxiii, [1], 692 p., plates. • Edmund Hoppe., *Geschichte der Physik*, p. 295-301. • John Rakovan and Glenn Waychunas., "Luminescence in minerals," *Mineralogical Record*, **27**, (Jan., 1996), p. 7-19. • W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

**REWORK:** Luminescence is the non-thermal emission of visible light by a substance. The emission of visible light by minerals in response to irradiation by ultraviolet light is a prime example. The principal mechanism for most types of luminescence is essentially the same, that is, the interaction of incident energy with electrons in a solid. One of the great scientific discoveries of this century is that the electron energy levels within an atom can have only discrete, specific values; that is, they are quantized. Because these energy levels have discrete values, the energy differences between levels are also quantized, and this provides the basis for explaining the mechanisms of luminescence in minerals.

There are numerous varieties of luminescence. Those produced by exposure to incident energy or radiation sources are distinguished by the type of incident radiation. Of the various types of luminescence two have had the greatest use by mineral enthusiasts and professional mineralogists. These are photoluminescence and cathodoluminescence. The primary reason for their popularity is the relative ease of producing ultraviolet light (for fluorescence) and an electron beam (for cathodoluminescence).

John Rakovan and Glenn Waychunas., "Luminescence in minerals," *Mineralogical Record*, **27**, (Jan., 1996), p. 7-19.

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The detailed summary of some key elements in the history of luminescent studies in minerals is well presented in the following books and reviews:

Walker G (1985) In: Berry F, Vaughan D (eds) Chemical bonding and spectroscopy in minerals chemistry. University of Birmingham

Waychunas, G., "Luminescence, X-Ray Emissionand New Spectroscopies," (pp. 638-698) in: F.C. Hawthorne, ed., *Spectroscopic Methods in Mineralogy and Geology*. Mineralogical Society of America, 1989. [Published as part of the series, *Reviews in Mineralogy*, volume 18.]

Leonard J. Spencer[401]

Gorobets B, Portnov A, Rogojine A (1995) Radiation Measurements 24: 485-49. [**electronic resource**]

Nasdala L, Götze J, Hanchar J, Gaft M, Krbetschek M (2004) In: Biran A, Lubowitzky E (eds) EMU Notes in Mineralogy, Spectroscopic Methods in Mineralogy vol 6, Chapter 2, pp 43-91.

Tarashchan, Arkadii Nikolaevich. (1978) Liuminestsentsiia mineralov. [Luminescence of minerals]. Kiev, Naukova Dumka, 1978. 296 p., illus. (in Russian) A classic, comprehensive treatise on luminescence, unfortunately not available in English translation, is the book Luminescence of Minerals by Tarashchan (1978) [DLC QE369.O6 T37].

Gorobets and Rogojine (2001) *Luminescent Spectra of Minerals*, contains a systematic compilation of luminescence spectra of minerals and also contains a summarization of the main achievements in the field upto 2000.

A good bibliography is in : Michael Gaft and Renata Reisfeld., *Modern luminescence spectroscopy of minerals and materials*. Berlin; New York, Springer, c2005. xvi, 356 p., illus.

M. Robbins (1983) *The collectors book of fluorescent minerals*. New York, Van Nostrand, 1983. 289 p.

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Cathodoluminescence observations of minerals and gems date back to the early work of Crookes (1879), who conducted spectral and polarization experiments. The book by Marshal (1988) cover its history and applications.[402]

D.R. Vij., *Luminescence of Solids*. 1998. xv, 427 p. : ill. [**QC476.5 .L86 1998**]

Nalwa, Hari Singh and L.S. Rohwer., *Handbook of luminescence, display materials, and devices*. Stevenson Ranch, Calif., American Scientific Publishers, c2003. 3 vols.

Curie, Daniel., *Luminescence in crystals*. London, Methuen; New York, Wiley, 1963. 332 p., illus. [**535.35 C975, tG2**]

Galanin, M.D., *Luminescence of molecules and crystals*. Cambridge, England, Cambridge

[401] L.J. Spencer., "Fluorescence of minerals in ultraviolet rays," *Nat. Hist. Mag (British Mus.)*, **1** (1928), p. 291-298.

[402] D. J. Marshall., *Cathodoluminescence of geological materials*. Boston, Unwin Hyman, 1988. 146 p. [**QE431.5 .M365 1988**]

International Science Publishing, 1996. 130 p., illus. [**QC476.5 .G34 1996**]

Leverenz, Humboldt W., *An introduction to luminescence of solids*. New York, Dover Publications [1968]. xxii, 569 p., illus. [ **QC476.5 .L38 1968**; "An unabridged and corrected republication of the work first published in 1950 ... The author has written a preface to the Dover edition, and a new Early history of luminescence ... and has replaced the periodic chart with a new one."]

T.C. O'Haver., "The development of luminescence spectrometry as an analytical tool," *Journal of Chemical Education*, **55** (1978), p. 423-428.

Malley, Marjorie., "Thermodynamics and cold light," *Annals of Science*, **51** (1994), p. 203-224. ['During the late 19th century, interest in thermodynamics led to several attempts to apply it to the puzzling phenomena of phosphorescence and fluorescence. These efforts reveal the pervasiveness of heat concepts for both experimental and theoretical physics of the period.'.]

### 5.4.1 Phosphorescence[403]

**REWORK:** The oldest known written observations on bioluminescent phenomena in nature were made in China, dating roughly from 1500 to 1000 B.C. regarding fireflies and glow-worms; however, no effort was directed at understanding and applying knowledge of such phenomena until the full flowering of alchemy in Europe during the 16th and 17th centuries. Aristoteles' (Greek: ???????) is the first to remark that Holzschwamm, sheds of fish the ability have decaying meat to shine in the dark.

Later still special cases are probably communicated, but this characteristic seemed to be only with organic bodies. With inorganic substances phosphorescence was first mentioned in 1612 by La Galla in *De Phaenomenis into Orbe Lunae*, 1612.[404]

1640: Fortunio Liceti, *Litheosphorvs, Sive De Lapide Bononiensi*, a phosphorescent barite is described. A work on the phosphorescent stone of Bologna. Kopp says that the first chemical preparation known to show phosphorescence was a paste made from a barite found near Bologna, and that it was described in this book. This is the most comprehensive 17th century work on the subject, and at the same time it is the least scientific approach. In the 55 chapters there is a detailed account of the various names by which the Bolognian stone was known, its discovery, the places where it occurred, and an attempt at explanation of its luminescence.

1665: Boyle suggests at least that first of Kircher (Mundus subterraneus, 1665, p. 210) described sea lights with the observations of the Aristoteles in connection of conditions (Phil, mentioned above. Trans. 59, p. 450).

1671: A. Kircher described in detail the manufacture of artificial phosphor from the Bologian stone.[405] He means, air contains a fine vapor, which can be illuminated easily; from this vapor aspirate the stone and radiate then in the dark one this up-sucked light.

1698: The first chemical investigation of the Bolognian stone, which is however incomplete, was made by Luigi Marsigli[406] In the meantime however different were "Phosphore " discovered 1676 observed spades pool of broadcasting corporations shining the vacuous tree in the Quecksilberbarometer when vibrating and called the same Merkurial phosphorus.[407] Only Hauksbee (f 1713) showed that this did not have to do anything with phosphorescence.[408]

Balduin made in 1675 an artificial phosphorus of Kalkerde and nitric acid, which when it was no longer in contact with air lost its phosphoresce, therefore to be hermetically

[403] Further historical information may be found in: E. Harvey., *A history of luminescence, from earliest times until 1900*. Philadelphia, American Philosophical Society, 1957. xxiii, [1], 692 p., plates. • Edmund Hoppe., *Geschichte der Physik*, p. 298-301. • W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

[404] La Galla., *De phaenomenis into orbe lunae*. 1612.

[405] A. Kircher, *Acre de Magna*. 1671, p. 18.

[406] L. Marsigli., Acta Erud., 1698, p. 148.

[407] Hist. Paris II, p. 202, 1733.

[408] Hauksbee, *Phil. Trans.* 1705, No. 303, p. 2129, and 1706, No. 307, p. 2277, 2327).

locked kept had.[409] Balduin wanted to make gold, the same goal that Brandt had. He made a real phosphorus from the urine, 1669/77. [410]

Oldenburg (1705) described the luminescence of fluorite, CaF2, on heating.[411]

Charles-François De Cisternai Du Fay (1698-1739) rediscovered the observation first made by Albertus Magnus that some diamonds would shine in the dark.[412] In 1730 he returned to the subject, phosphorescence, with a memoir of great importance in the development of his method. he noted that some limestones, marbles, and gypsums phosphoresced.[413] He also found the property with some emeralds and other jewels.[414]

Chemists had long been acquainted with a few minerals which, like the Bologna stone (BaS) and Balduin's hermetic phosphor (CaS), glowed after exposure to light. Great mystery surrounded these expensive and supposedly rare substances. Dufay detested mysteries and held as a guiding principle that a given physical property, however bizarre, must be assumed characteristic of a large class of bodies, not of isolated species. He set about calcining precious stones, egg and oyster shells, animal bones, etc., most of which became phosphorescent; indeed, he found that almost everything except metals and very hard gems could be made to shine like Bologna stones. He gave clear recipes for producing the phosphors and patiently examined the endless variations in their colors and intensities: "How differently bodies behave which seemed so similar, and how many varieties there are in effects which seemed identical!" This line of work ended in 1735, with a study of the luminescence of gems. Dufay distinguished excitation by friction, by heat, and by light, and tried to find some general rules of their operation; but the phenomena proved altogether too complex, and he established little more than that diamonds usually can be excited in more ways than lesser stones. (DSB) In 1735 Dufay wrote on the luminence of diamonds.[415]

A number of works appeared in the 18th century that described phosphorescent substances that exhibited the property under certain circumstances. I lift Lane [1734-1807] observed in 1764 that marble was made to phosphorescence by an electrical spark.[416]

Placidus Heinrich (1758-1825) summarized all the previous investigations implemented until that time in a large work that covered light generation and phosphorescence that was published as *Die Phosphorescenz der Körper* (4 vols., 1811-1820). He gives therein a sequence of the phosphorescing bodies, of the best, the fluor-spar, lime inter etc. up to the Marienglas. The first section deals with phosphorescence from light, the second treats thermoluminescence, the third light from plants and animals, the fourth, luminescence from mechanical means, and the five light from chemical reactions. In 1840 Heinrich made the discovery that a phosphorescing body, which had lost its phosphorescence by heating regained the ability through exposure to a powerful the electrical spark.[417]

From V. Grotthuss examines the conditions, under which the bodies phosphoresce; some had this characteristic only in presence of oxygen, primarily are that the organic Phosphore. Furthermore he finds that the jets are most suitable from blue to deep into the ultraviolet.[418] V. Grotthuß already dedicated a longer investigation in a larger number of work E examined. [419]

In 1830 T.J. Pearsall observed that col-

[409] Balduini aurum superius etc. et phos phos-phorus hermeticus, 1675).

[410] Brandt., *Miscel. Berolin.*, I, p. 91.

[411] Oldenburg, H. (1705). Four sorts of factitious shining substances. Philos. Trans. Abr. 3, 345-346.

[412] Albertus Magnus., *Opera.* Lyon, II, 4.

[413] C.-F. Du Fay., "Mémoire sur un grand nombre de phosphores nouveaux," *Mémoires de l'Académie des Sciences (Paris)*, 1730, p. 524-535.

[414] Fay., *Mémoires de l'Académie des Sciences (Paris).* Paris, 1734/36, p. 503.

[415] C.-F. Du Fay., "Recherches sur la lumière des diamants et de plusieurs autres matières," *Mémoires de l'Académie des Sciences (Paris)*, 1735, p. 347-372.

[416] Lane., *Phil. Trans.* 56, p. 107.

[417] Pogg. Ann. 49, p. 544.

[418] Grotthuß., *Schweigg. Journ.*, 3, 1811; 14, p. 133, 1815.

[419] V. Grotthuß., Schweigger to this behavior. Journ. 1814.

orless fluorite could be colored by discharging sparks from a Leyden jar against it.[420]

1835: Heinrich Rose [421]

1852: G.G. Stokes[422]

1859: Edmond Becquerel[423]

1867: A. Forster[424]

1871: A. Forster investigated the effect high temperature had on phosphorescence.[425]

In 1874 Daniel Hahn published his dissertation on the subject on the phosphorescence of minerals.[426]

In 1859 E. Becquerel investigated phosphorescence and his results are summarized in a series of papers.[427] of his in summary in *La lumiere*, SA cause et ses effets (1867). In it also the experiments are to the proof that the color of the phosphorus light with the temperature varies. Above all crosswise eischen investigations interest those from this Bec, which refer to the time and "fading away " shining after the exposure (L.C., p. 244). He also showed within a short time the law of phosphorscening bodes: at longer duration it fails perfectly against it. Likewise the law that the Phoephoreszenz color is less brechbar than the exciting, is only one rule, also the exceptions has.

In the 19th century, Becquerel showed that phosphorescence in solids is due to the presence of finely dispersed foreign substances. Since then, numerous workers have studied the luminescence of crystals under the action of ultra-violet radiation, cathode rays, X rays and a, p and y radiation. He made a detailed study of phosphorescence and fluorescence, two phenomena with which physicists had long been familiar. With a special instrument, the 'phosphoroscope', he showed that the duration of phosphorescence varies from substance to substance, and suggested that fluorescence is simply phosphores cence of very short duration. Subsequent investigations fully proved the justice of his view.

Becquerel designed for his measurements his own phosphoroskope, which is still used to this day.[428] This led to further improvements in the phosphoroskope, particularly by the installation of a special engine. Wiedemann in order particularly to use as source of light the electrical spark,[429] while Lenard designed a very simple phosphoroskop.[430]

It was in the papers mentioned above several times the question was raised, whether the phosphorescence occurs substantially by the heating up, there also the Eeibung (particularly with the phosphorus) the phosphorescence to excite can. This question decided Kirchhoff there occasionally its famous work on the solar spectrum (see below) already that phosphorescing is not a pure effect of the warmth, but by changes in the body is brought out.[431]

1885: Becquerel E. (1885, 1886) Étude spectrale des corps rendus phosphorescents par

[420] T.J. Pearsall., "On the effects of electricity upon minerals which are phosphorescent by heat," *Journal of the Royal Institution*, **1** (1830), p. 77-83. • *ibid.*, "Further experiments on the communication of phosphorescence and colour to bodies by electricity," *Journal of the Royal Institution*, **2** (1830), p. 267-281. • *ibid.*, "Ueber die Wirkung der Elektricität auf die bei Erwärmung phosphorescirenden Mineralien," *Annalen der Physik*, **20** (1830), p. 252-260.

[421] H. Rose., "Über die Lichterscheinungen bei der Krystallbildung," *Annalen der Physik*, **35** (1835), p. 481-485, **52** (1836), 443-464, 585-600, and *Ann. de Chim. et Phys.*, **61** (1841), p. 288-293.

[422] G.G. Stokes., "On the change of refrangibility of light," *Philsophical Transactions*, **142** (1852), p. 463-562 and **143** (1853), p. 385-396.

[423] E. Becquerel., "Recherches sur divers effets lumineux qui resultent de l'action de la lumière sur les corps" (1st, 2nd and 3rd Mémoires), *Ann. de Chim. et Phys.*, **55** (1859), p. 5-119; **57**, p. 40-124.

[424] A. Forster., "Ueber Darstellung künstlicher Leuchtsteine," *Mitteilungen der naturforschenden Gesellschaft in Bern*, 1867, p. 62-131.; *ibid.*, "Ueber Darstellung künstlicher Leuchtsteine," *Annalen der Physik*, **133** (1868), p. 94-121, 228-258.

[425] A. Forster., "Notiz zur Kenntniss der Phosphorescenz durch Temperaturerhöhung," *Annalen der Physik*, **143** (1871), p. 658-660.

[426] D. Hahn., *Die Phosphorescenz der Mineralien.* Wittenberg, 1874. 37 p.; *ibid.*, "Die Phosphorescenz der Mineralien," *Zeitschrift für die Gesammt. Wissenschaften* (Berlin), **9** (1874), p. 1-37, 131-213.; Abstracted English translation, "On the phosphorescence of minerals," *Edinburgh Geological Society, Transactions*, *3* (1880), p. 41-49.

[427] E. Becquerel., "Recherches sur divers effets lumineux qui resultent de l'action de la lumière sur les corps" (1st, 2nd and 3rd Mémoires), *Ann. de Chim. et Phys.*, **55** (1859), p. 5-119; **57**, p. 40-124.

[428] E. Becquerel., *?????*, p. 249.

[429] Wiedemann., *(Wied. Ann.* 84, p. 450, 1888).

[430] Lenard., *(Wied. Ann.* 46, p. 634, 1892.

[431] Kirchhoff., *Abh. Berlin*, 1861, p. 38).

l'action de la lumière ou par des décharges électriques. Comptes Rendus Acad. Sci. Fr. 101, 205-210. Action du manganèse sur le pouvoir de phosphorescence du carbonate de chaux. 103, 1098-1101. Observations on Iceland spar. E. Becquerel (1885), in a study of cathode rays, found that when crystals were bombarded by cathode rays they became coloured and also emitted light.[432]

Since by all attempts over fluorescence and phosphorescence it had shown up that the cause of this light sending is not rise in temperature, then E. Wiedemann suggested for all light sending, which was independent of the rise in temperature more or less, to the name luminescence and wants, if exposure arranged the luminescence, Photolumineszenz for designation to then use, according to Elektrolumineszenz etc. (Wied. Ann. 34, p. 446, 1888).

Goldstein (1894) showed that ultraviolet light has the same effect as cathode rays.[433]

Holtzknecht (1902) showed that X-rays produce colouration in various crystals.[434]

The phosphorescence of zinc sulfide under X-ray bombardment was discovered in 1903, independently by Crookes[435] and Elster & Geitel.[436]

In 1910 the subject was written up in Radium and Colour by Doelter in his *Radium and Colour*.[437]

Röntgen (1921) determined the absorption spectra of coloured crystals and also their photoconductivity.[438]

1956: Przibram published a comprehensive survey under the title *Irradiation Colours and Luminescence*.

There are many comprehensive references in the literature listing minerals that luminesce:

HENKEL, G. (1989) The Henkel Glossary of Fluorescent Minerals.

ROBBINS, M. (1994) Fluorescence, Gems and Minerals Under Ultraviolet Light. Geoscience Press, Inc., Phoenix., 1994.

Literature

1874 Daniel Hahn., "Die Phosphorescenz der Mineralien," *Zeitschr. Gesammt. Naturwiss.*, **9** (1874), p. 1-37, 131-213. Abstracted English translation, "On the phosphorescence of minerals," *Edinburgh Geol. Soc. Trans.*, *3* (1880), p. 41-49.

### 5.4.1.1 The Bologna Stone[439]

**REWORK:** By that time, the philosophical and intellectual groundwork that permitted a rational and materialistic approach to the study of natural phenomena had been laid and, in the spirit of times, this approach was applied to finding or making the Philosopher's Stone, that which would be capable of turning "ignoble metals" into gold. Conditions were thus ripe for excitement when, in 1602, one Vincenzo Casciarolo, a cobbler by trade and dilettante alchemist, discovered the "Bolognian Phosphorus" on Monte Paderno just outside of Bologna. It was this natural stone, subsequently referred to also as the "Bolognian Stone" or "Litheophosphorus", that became the first object of scientific study of luminescent phenomena.

The most complete text on the subject of Vincenzo Casciarolo and his stone, "Litheosphorus Sive De Lapide Bononiensi" (Fig.2), was written in 1640 by the scholar and professor of Philosophy at the University of Bologna Fortunius Licetus (1577-1657), of which the following is an excerpt in translation from the original Latin text:

"About thirty-six years ago, a stone of this type was found in the countryside near Bologna by an honest man of humble circumstances who

[432] Becquerel, E. (1885). Etude spectrale des corps rendus phosphorescents par l'action de la lumière ou par les décharges électriques. C. R. Acad. Sci. 101, 205-210.

[433] Goldstein, E. (1894). Über die Einwirkung von Kathodenstrahlen auf einige Salze. Sitzungsber. K. Preuss. Akad. Wiss. Berlin, pp. 937-945.

[434] Holtzknecht, G. (1902). Ueber die Erzeugung von Nachfärben durch Röntgenstrahlen. Verh. Dtsch. Phys. Ges. 4, 25-28.

[435] Crookes, W. (1903). The emanations of radium. Proc. R. Soc. London Ser. A, ĩ, 405-408.

[436] Elster, J. & Geitel, H. (1903). Über die durch radioaktive Emanation erregte scintillierende Phosphoreszenz der Sidot-Blende. Phys. Z. 4,439-440.

[437] Doelter, C. (1910). Radium and Colour. Dresden.

[438] Röntgen, W. C. (1921). Über die Elektrizitätsleitung in einigen Kristallen und über den Einfluss einer Bestrahlung darauf. Ann. Phys. (Leipzig), 64, 1-192.

[439] Further historical information may be found in: Partington, *History of Chemistry*, 1961, **2**, p. 334-340. • E. Harvey., *A history of luminescence, from earliest times until 1900*. Philadelphia, American Philosophical Society, 1957. xxiii, [1], 692 p., plates. • E. Hoppe., *Geschichte der Physik*, p. 298-301.

was given to assiduous pursuit of activity in the science of chemistry; he was called Vincenzo Casciarolo, and he was of Bolognian origin. As asserted by the Excellent Petrus Poterius Andegauensis, the illustrious chemist now among the Bolognians, in his "Pharmacopea Spagirica", Casciarolo who abandoned his work as a cobbler to pursue transformation of humbler materials into gold, took the stone that he called "solar" to Scipione Begatello, an expert in the art of transformation in that time. [Casciarolo] sustained that the stone was most suitable for the production of gold by virtue of its notable weight and content of sulphur. After submitting the stone to much preparation, it was not the Pluto of Aristophanes that resulted; instead, it was the Luciferous Stone, which woud not itself produce gold, but which would absorb the golden light of the sun, like a new Prometheus stealing a Celestial Treasure. Casciarolo communicated this wonderful and unexplained event not only to Begatello, but also to the Illustrious Antonio Magino, the excellent Professor of Mathematics in this Archiginnasio [of the University of Bologna]. Magino gave preparations of the stone as a gift of a wonderful and unheard-of substance to several men of letters and to many others as well. I myself, in the company of the Illustrious Carolo Antonio Mangino, Bolognian philosopher, have seen many stones made of this substance, whether in their natural or calcinated form, whole or fragmented, alone or in mixture with albumin. With diligent observation, again and again I have seen the conception of the light of the Sun, the glowing in the darkness, and the spontaneous extinction. I went with the Illustrious Ovidio Montalbano, noble interpreter of the mathematical arts in our Palladium [University of Bologna], and with Carolo Antonio Mangino, Philosopher, to Monte Paderno, the place of origin of the stone, and the surrounding valleys, and I collected many stones of this substance made, most suitable for producing light".

The rudimental alchemistic approaches of the cobbler Casciarolo led, by a process of heating and calcination of the stone, to the discovery of its mysterious and magical ability to "accumulate" light when exposed to the sun and to emit it in the darkness.

The recipe and method of preparation of the Bolognian Stone were kept secret only briefly, the first detailed description on the methods being published in 1625 by Pierre Potier (Poterius), physician to the King of France, in his "Pharmacopea Spagirica", a treatise on inorganic remedies based on the teachings of Paracelsus. Potier lived for some time in Bologna, and he was able to give an acceptable interpretation of the discovery.

Casciarolo showed his "lapis solaris" to many learned men of the time, and there was widespread interest in Italy despite the fact that attempts to use it as the "Philosopher's Stone" were unsuccessful. Galileo Galilei (1564-1642) participated in scientific debate regarding the stone, and he also presented it to Giulio Cesare La Galla (1576-1624), professor of Philosophy of the Collegio Romano who first reported this phenomenon in the book "De Phenomenis in Orbe Lunae" (Venice, 1612). La Galla asserted that the untreated stone was not able to emit light, but that it acquired this property only after calcination. He explained this phenomenon, as related to him by Galileo, as a certain quantity of fire and light to which the stone was exposed being trapped in the stone and then slowly released from it, comparing its absorption to that of water by a sponge.

Subsequently, Ovidio Montalbani (1601-1671), professor of Astronomy and Mathematics at the University of Bologna, published a brief report, "De Illuminabili Lapide Bononiensi Epistola" (1634), in which he gave a dissertion on the various colors of light that could be obtained from the stone, and was the first to suggest that the light resulted from a kind of burning. As mentioned above, the most important and comprehensive contribution to the subject was given by Fortunius Licetus (15771657) in his lengthy (280 pages) treatise of 1640, "Litheosphorus Sive De Lapide Bononiensi". His approach was detailed and very enthusiastic, so much so that publication of the book led to a famous controversy between himself and Galileo Galilei: whereas Licetus sustained that the faint light of a crescent moon

was produced by phosphorescence similar to that of the Bolognian Stone, Galileo believed that it was a reflection of sunlight from the Earth to the Moon. The debate extended throughout Europe, aided by the fact that the Bolognian Stone was included in Pierre Potier's widely used "Pharmacopea Spagirica" (1425), where it was mentioned for its presumptive depilatory properties.

This use of the stone was noted by French and German physicians and pharmacologists until the 18th century. Another important European contributor to the study of the stone was given by Athanasius Kircher of Fulda (1601-1680) who, during his sojourn in Rome, wrote two books on the subject, "Magnes Sive De Arte Magnetica" (1435) and "Ars Magna Lucis Et Umbrae" (1646). To Kircher, the ability of phosphorus to attract light was similar to that of a magnet for iron, and his studies led him to believe that the material was made porous by calcination, thereby holding the subtle vapors of air suffused with light in its pores.

John Evelyn (1620-1706) was one of the first Englishmen to learn of the stone during his visit to Bologna in 1645. Although he apparently observed the luminescence, confirming that it occurred with various colors of light, he did not take any samples back to England because, as was reported in the "Philosophical Transactions of the Royal Society" in 1666, the recipe for the preparation of the stone had apparently been lost. The most important contribution of the mid-17th century to understanding of the phenomenon came from Nicola Zucchi (1586-1670), a professor of Mathematics at the University of Rome. In 1652 he reported in his book "Optica Philosophia" that the more intense the light to which the Bolognian Stone was exposed, the more strongly it luminesced, and also that the color of the light emitted by the stone was the same regardless of whether it was exposed to white light or that passed through red, yellow or green glass. From this he concluded that the light is not merely absorbed as such.

Although his experiment was very important, it was not repeated until almost a century later when, in 1728, a group of scientists in Bologna led by Francesco Maria Zanotti renewed the study of phosphorus, arriving, however, at an interpretation that was entirely different from the one commonly held at the time. In his experiments with the Bolognian Stone Zanotti showed that it did not soak up the light like a sponge but that the light coming from the stone was its own.

They essentially repeated Zucchi's experiment, aided by Count Luigi Ferdinando Marsigli, Bolognian naturalist and mathematician.

In 1691, Marsigli wrote "Del fosforo minerale e sia della pietra Bolognese" and dedicated it to his English colleague Robert Boyle, who unfortunately died before he was able to read it; because of Boyle untimely death, the work was put aside and not published until 1698. Several decades later, Count Camillo Galvani wrote in his tract "Sulla pietra fosforica del bolognese" (1780):

Many other prominent men searched for the Bolognian Stone or visited Monte Paderno, among them Goethe in 1786. Today we have a vastly more comprehensive understanding of the Bolognian Stone and its ability to luminesce. We know it is made of barite (barium sulphate) in the form of heavy silvery concretions with fibrous radial formations that widen toward the periphery of the stone.

The phenonenon discovered by Casciarolo was the first recorded observation of inorganic phosphorescence. In these earlien times, the scientific dimensions of studies were often tinged with a magical quality that has, perhaps unfortunately, now largely disappeared. Even in the popular mind, this discovery was perceived as wondrous and momentous, and awareness of the stone was so common that in Bologna it was even employed in satire, as a metaphor for the splendor of the reigning Prince.

I have had the good fortune of being born and raised in Bologna, and I still remember when, as a young student charmed by magical aspect of studying minerals and chemicals, I ventured along the path taken by Casciarolo, over the Calanques of the Colli bolognesi (Bolognian Hills) to Monte (Mount) Paderno, less than three miles from the center of Bologna. I can still remember the excitement

I felt when I found my first Bolognian Stone, a piece about the size of an orange, which still has a place of honor in my collection.

When my friend and colleague Anthony Campbell of the University of Cardiff (Wales), who has a passionate interest in Natural History, recently came to Bologna to give a series of lectures I was more than happy to accomodate his request that I accompany him to the same area around Monte Paderno to look for the Bolognian Stone. Although we were not successful in this regard, we did found or perhaps, refound, the enthusiasm and excitement of our earliest days of scientific exploration. It was great fun!

Almost four hundred years have passed since the discovery of the Bologna Stone. Since then, the earlier occult studies, filtered by illuministic rigor, have given way to a modern scientific approach that has produced a vastly greater knowledge of luminescent phenomena, including recent acquisitions in the fields of bioluminescence and in genetic manipulation.

Nonetheless, the phenomenon of luminescence remains a fascinating field of study that still has a magical quality, at least for those of us who remain young at heart. We of the University of Bologna are proud of its history; indeed, in its more than nine hundred years of existence many other chapters have been written in the history of science.

We would like to extend an invitation to all who are interested in these fascinating stories to visit the University and the city of Bologna.

### 5.4.2 Fluorescence[440]

**REWORK:** Fluorescence was first observed by Kircher (1601-1680) at a solution (Tinktur) of the wood specified by the inhabitants of Mexico Tlapazalli (lignum nephriticum), which translucently knows, in the reflected light appeared blue. Naturally, " Kircher saw also still many other miracle things to it, but to supply the explanation he did not hold its promise (acre magna lucis umbrae, 1671, et p. 56).

Boyle took up this discovery, stated that she looks reflecting blue translucently gold-yellow. It compares this feature with probably the remark made first by Harriot that goldbeater's skin is transparent, but then appears green blue (Epist. ad Kepler, 235, 1607), and explain to pass the thing by it that these bodies would have the characteristic to back-throw individual kinds of light others; that was also Newton's theory (Exper. et cons. de col. III, No. 9 and 10, 1663).

More than 100 years no more obersvations were apparently made. Wish determined the feature at the same Tinktur again, only it calls the colors blue and red; with Safran he wants to have seen yellow red and green, and/or. It filled a prism with Indigo, then red was absorbed, that reflected Light appeared blue white (verse. and Beob. over the colors, 1792).

Again later Brewster the feature at sulfur-sour Chinin showed 50 years, by throwing a cone of sunlight into a Glastrog filled with it by a lens; this cone shone sky-blue, while the let through light appeared white. Chlorophyll, which already of wish was examined, gave blood-red cone, translucently brownish-red; Kurkumatinktur supplies becomes green to cone, translucently yellow-brown; Fluor-spar: Cone violet-blue, translucently knows. It called the procedure internal Eeflexion " (Eep. OF roasted. Assoc. 1888, p. 10, and Edinb. Trans. 12, p. 542, 1846).

Herschel called the feature epipolische dispersion " (Phil. Trans. 1845, p. 143). In a very detailed work, which proceeded from the fluor-spar, Stokes (1819-1903) particularly examined conditions at Chininlösung and called this characteristic fluorescence (Phil. Trans. 1852, p. 463). He observed also first the difference whether one observes the reflected light by a body, or whether one lets the light pass through before the Eeflexion by the body. Then it examined fluorescence with the Spektralfarben and found that the jets of largest Brechbarkeit, particularly the

[440] Further historical information may be found in: E. Harvey., *A history of luminescence, from earliest times until 1900*. Philadelphia, American Philosophical Society, 1957. xxiii, [1], 692 p., plates. • Edmund Hoppe., *Geschichte der Physik*, p. 295-298. • Fred W.D. Rost., "Chapter 18. The history of fluorescence microscopy," (**2**, pp. 183-195) in: *Fluorescence microscopy*. New York, 1995. [Deals mostly with 20th century applications.] • W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

ultraviolet jets, which produce fluorescence. It expresses the general sentence: In the fluorescence light the Brechbarkeit is smaller than in the light producing fluorescence. It divides the spectrum produced on a Fluoreszenzschirm by view by means of one prisms turned around 90° into two parts (Pogg. Ann., Ergb. 4, p. 188, 1853).

Hagenbach (1833-1910), the 36 substances examined, confirmed the Stokesschen sentence and found the brightness maxima of the fluorescence light (Pogg. Ann. 141, p. 248, 1870; 146, p. 66, 282, 375, 508, 1872).

Against the fact Lommel showed that there are also exceptions of the Stokesschen sentence (ib. 143, p. 30, 1871; 159, p. 514, 1876; 160, p.75, 1872; Wied. Ann. 3, p. 113, 1878).

Lallemand (18161886) found from it in such a way designated ISO-chromatic " fluorescence (Journ. D. Physical 5, p. 829). Due to these experimental results Lommel developed then its theory of the absorption and fluorescence, whereby he understands the absorption as a kind Eesonanzerscheinung, after which the fluorescence light of in such a way changes swinging atoms is sent (Wied. Ann. 3, p. 251). Those are thoughts, which remind Euler (see above) lively of the conceptions of L. Whereupon Lommel creates then its theory of the normal and abnormal dispersion (ib., p. 889), which it against different on seized defended. It participates from interest that he can harmonize its formula also with the Helmholtz one.

Helmholtz had derived from the motion equation of the ether and the resonant atoms as feed back control systems the dispersion equation, which Eechnung quite laborious by the necessary regulation of four constants required.

Lonimel showed now that one actually gets along with one Näherungsformel and two constants for all m rmal dispersing media (ib. 8, p. 628, 1880).

The work of Sellmeyer and helmet Helmholtz arranged chaining eggs to develop its dispersion theory also in such a way now that it also contained the abnormal dispersion (Wied. Ann. 7, p. 608, 1880). It had however already shown up that also with Adsoptionsstreifen with some approximation the simple formula is still sufficient (S. Wüllner, Wied. Ann. 17, p. 580, 1882).

That also for gases (spec. Air) dispersion to find is, is recognized only late. Mail intended first only the Brechungskoeffizienten for white light.

After Euler the refraction of light in the atmosphere as a function of the temperature and/or on the tightness had already computed (Mem. Berlin 1754, p. ), the Brechungskoeffizient is again certain 631 by Delambre (Laplace, Mec. cel. 4, p. 237, 1805) from atronomischen observations. By compression of air Biot and Arago (Mem observed. Of Paris 7, p. 301, 1806) and found the relationship between Brechungskoeffizienten and density expressed const by the equation (n l) /d =.

Only chaining eggs took these attempts by observation with min see Interferentialrefraktometer (see above) and determined thereby n iür the woman yard see lines on three places exactly (Pogg. Ann. 124, p. 390, 1865).

Kind of MASK works likewise with interference and intends the Brechungskoeffizienten for the D-line and four cadmium lines (Ann. de l'ec. standard. 6, p. 9, 1877). Again with apparatus sees min working Chappuis and find Eiviere and (n l) /d really constantly (Ann. de Chim. et de physical ones, Ser. 6, 15, 1888).

Benoit (1844-1922) observes the dependence on the temperature (Journ in Newton's a gene. de physical ones 8, p. 451, 1889). In extremely careful investigation with a Eowlandschen Konkavgitter Kayser and Eunge have the dispersion of air as a function of the wavelength intended for the lines A to U of the Fraunhoferschen designation (Wied. Ann. 50, p. 293, 1893). It was shown with the fact that one does not get along here with two members of the Cauchysehen formula, but only with three constants agreement between observation and formula to manufacture can.

The investigation of the dispersion had referred up to then only to the visible spectrum; it was however probably tried with the fluorescent substances to make it usable also for ultraviolet light but within the range of the infrared jets was only for quartz by Mouton

(C.R. 1879, p. 1078, 1189) and for rock salt of Langley (Wied. Ann. 22, p. 598, 1884) a Eeihe implemented by dispersion measurements.

Only Rubens measured the dispersion of infrared jets by extraordinarily elegant method (Wied. Ann. 45, p. 238, 1892). This work was in repeated relationship starting point for later investigations, which lie outside of the framework of this book.

The existence of ultraviolet (UV) light, and the phenomenon of fluorescence were first recognized in the early nineteenth-century from the observation that when light was dispersed by a prism, the region beyond the farthest violet visible light could darken photosensitive silver salts and cause minerals and other substances to luminesce. The term "fluorescence," coined by George G. Stokes in 1852, was .derived from the behavior of fluorite when exposed to UV light. Early observations of fluorescence required cumbersome arrangements of sunlight, window shades, and prisms in darkened rooms, so that only the most intense examples of fluorescence, produced by UV wavelengths closest to those of visible light, could be detected. Other early observations were made with radiation from radium salts, burning magnesium metal, or electric arc lamps, often involving a great deal of heat, light, smoke, noise, or danger to the participants. One of the first published studies of fluorescent minerals was by Kunz and Baskerville (1903), who examined the luminescence of gems and gem minerals in the Morgan collection of the American Museum of Natural History. They employed radium, X-ray "Roentgen rays," and an electrical spark between iron electrodes. Later, when UV lamps came into common use, observation of fluorescence became much easier and more convenient. Spencer (1929), Harvey (1957), and Robbins (1983) give accounts of some of these early observations.

Spencer (1929)

Harvey (1957)

Robbins (1983)

Liebisch., Fluorescence in ultra-violet light; , Ber. Ak. VViss., 229, 1912.

## 5.5 Hardness[441]

**REWORK:** Hardness is defined as the resistance of a smooth surface of a mineral to abrasion, while the degree of hardness is determined by observing the comparative ease or difficulty with which one mineral is scratched by another, or a file or a knife. Within the realm of minerals, there are all grades of hardness, from talc, impressible by the finger-nail, to the diamond, hardest of all natural substances. Measurements of hardness are extremely useful in the determination of mineral species. Unfortunately, hardness is a very vague concept, and what we, in fact, do when we try to measure it, is to measure a complex of such diverse properties as elasticity, malleability, toughness, viscosity, etc.

The cohesion strength of crystals was not the subject of many early scientific investigations and it is still suprising that there have been relatively few observations in the early literature about the hardness of minerals. Fromt eh earliest experiments, optical, thermal, magnetic and electrical features of crystals were well studied and theorized about but ideas on the hardness are noticeablly lacking. This is particularly odd since observations on hardness could be performed with less difficulty than most other physical properties.

That gemstones and other minerals were of differing hardness must surely have been known since the earliest times and as a mineralogical science developed authors would note that one mineral was harder than another mineral.

[441] Further historical information may be found in: Ulrich Burchard., "The sclerometer and the determination of the hardness of minerals," *Mineralogical Record*, **35** (2004), p. 109-120. • William J. Grailich and F. Pekárek, "Der Sklerometer, ein Apparat zur genaueren Messung der Härte der Krystalle," *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften. Mathematisch-Naturwissenschaftliche Classe* (Wien), **13** (1854), p. 410-436. • Frédéric Hugueny., *Recherches experimentales sur la dureté des corps*. Paris and Strasbourg, Gauthier-Villars, 1865. vii, [1], 109 p., 6 plates. • Albrecht Schrauf., *Lehrbuch der physikalischen Mineralogie*. Leipzig, 1866, **1**, p. 61-70. • H. Tertsch, *Geheimnis der Kristallwelt*, 1947, p. 206-211. • Isaac Todhunter., *A history of the theory of elasticity and of the strength of materials. From Galilei to Lord Kelvin*. London, 1886-93. 3 vols. xiv, [2], 936 p.; xii, [2], 762 p.; [4], 546 p. • Samuel Robinson Williams., *Hardness and hardness measurements*. Cleveland, The American Society for Metals, 1942. [8], 558 p. ["Bibliography on hardness," p. [463]-546.]

Diamond was clearly known for its hardness as its ancient name (adamant=???) clearly defines. The relative hardness of other stones was implicitly known by the miners, stone masons and ancient jewelers if not explicitly recorded. This is attested to by the fact that early works of art and utility were carved from rock crystal, and other precious stones.

In 1546, Agricola recognized that hardness could be one of the properties used to distinguish metals and minerals, but did not persue the subject further. Instead, the first scientific approach to hardness was presented by the physicists.

Petro van Musschenbroek Musschenbroek concludes his *Physicae Expérimentales ei Geometricae Dissertationes* (Leyden, 1729) with a chapter entitled: "Tentarnen de corponim Duritiâ" (p. 668-672), that portion of his work (Introductio ad Cohaerentiam corporum firmorwn) to which we have referred in our Art 28*. His method, of which he speaks very diffidently, was to count the number of the blows of a mass swung like the bob of a pendulum which are required in order to drive a chisel through a slab of definite thickness of the given material. He supposes that the number of blows divided by the specific gravity of the material may be taken as a measure of its hardness. He tested in this way the hardness of a great number of specimens of wood and of some of the more usual metals. He gives the following ascending order of hardness for metals: lead, tin, copper, Dutch silver of small value, gold, brass, Swedish iron. Obviously Musschenbroek's definition of hardness would involve absolute strength rather than set.

Petro van Musschenbroek thought he was measuring hardness when he counted the number of blows necessary to drive a chisel through a given thickness of the material to be tested, and divided this number by the specific gravity of the material.[442] In this fashion Musschenbroeck measured the hardness of a large number of woods and of the common metals. His metals were arranged in ascending order of hardness as follows; lead, tin, copper, Dutch silver, gold, brass and Swedish iron. Musschenbroek in his *Introductio ad Philosophiam Naturalem* (1762) has in the first volume a chapter Cap. XVI. De Corpore Duro, Fragili, Molli, Flexibili, Elastico that describes durability, fragibility, flexibilty, and elasticity. But the concept of an absolute hardness is still not clear. Here are described only relative values.

Anselmus Boëtius de Boodt [1550-1632] in his book *Gemmarum et Lapidum Historia* (1609) presents one of the most important mineralogical works of the seventeenth century, marking a transition over previous lapidaries. Discussing the properties of stones, Boodt gives a long discussion of hardness. He provides the earliest system of hardness grading for the various stones, which acted as a crude index to distinguish imatation gems from genuine. He distinguished three degrees of hardness and also included softness as a related but different property. Soft stones are considered such if fingers alone are sufficient to rub away the surface. Hard stones are called hard when they can neither be rubbed away with fingers nor cut by iron. Hard stones are classified under three categories: (1) a steel file can scratch the stone, (2) only the use of the Smyrna stone [emerald??] can cut the surface, and (3) those that can only be rubbed away with a diamond point.

However, it was not until the seventeenth century that the characteristic of hardness began to appear in the literature as a mineralogical property. Christian Huygens in his *Traité de la Lumière* (1690) noticed that a calcite cleavage has a different hardness along the axis rather than across it. Apparently this is the earliest reference to the scientific measure of hardness and the variation of hardness with direction. He suggested that the optical properties of Iceland spar could be explained by considering a crystal as being made up of flat spheroidal molecules. At the surface of the crystals these flat spheroids were arranged like the scales of a fish. If one moves a sharp edge with the scales, it slips over them, but if against the scales it catches under the

[442] P. van Musschenbroeck., *Physicae Expérimentales, et Geometricae, de Magnete, Tuborum Capillarium Vitreorumque Speculorum Attractione, Magnitudine Terrae, Cohaerentia Corporum Firmorum Dissertationes*. Lugdum Batavorum, S. Luchtmans, 1729. Chapter 10 of section, "Introductio ad cohaerentiam firmorum," pages 431-672.

edge of the scales and the slipping is not easy. He observes this same effect in applying the scratch method to the natural surfaces of Iceland spar. The scratch method, therefore, is a means of demonstrating the way in which the crystal is built. He finds that in one direction the scratching point moves easily but in the opposite direction it does not.[443]

In 1728, John Woodward in his *Fossils of all Kinds digested into a Method* (1728) used a minerals relative hardness compared to the hardness of marble as a diagnostic to help subjugate species within his method of mineral classification.

About 1730, Pierre Varignon [1654-1722] wrote about his experiences with the hardness of bodies.[444]

In the mid-eighteenth century Carl Linneaus recommended hardness has a distinguishing property of minerals but took no decisive step to use it in his own mineralogical works..[445] It was a theoretical leap to a complete scale of hardness that would provide a relative scale against which the hardness of any mineral could be compared against another.

In 1768, Bengt Andersson Quist [1726-1799] was apparently the first to propose a graduating scale listing the relative hardness of minerals.[446] In his study he compared 13 minerals with specimens coming from a variety of localities so that a range of hardness values could be established. His hardest stone was diamond with a value of 1 down to zeolith with a hardness of 13. He also included information on the specific gravities of the stones listed. Published in Sweden's leading scientific journal, Quist's paper influenced the great Irish mineralogist Richard Kirwan [1735-1812] to rework the index and incorporate it into the first edition of his own influential mineralogical textbook, *Elements of Mineralogy* published in 1784.[447] Here diamond is given the highest relative hardness value of 20 while other minerals are listed with decreasing values until chalk with a value of 3. Kirwan also gives information about the specific gravity of the minerals listed. However, in the second edition of his *Elements of Mineralogy* published in 1794, Kirwan abandons the list giving instead a general description of how to determine the value of relative hardness.[448]

| Mineral | Hardness | Sp. Gr. |
|---|---|---|
| Diamond | 1-3 | 31-34 |
| Ruby | 4-8 | 31-42 |
| Sapphire | 4-5 | 36-38 |
| Topaz | 6-7 | 35-45 |
| Emerald | 9 | 27-28 |
| Aquamarine | 9 | 28 |
| Chrysolite | 11 | 36-37 |
| Garnet | 9-11 | 33-44 |
| Rock Crystal | 9-10 | 26-28 |
| Quartz | 11 | 22-29 |
| Agate | 9-10 | 25-27 |
| Jasper | 10-12 | 20-27 |
| Zeolite | 13 | 19-21 |

Quist's Scale Abridged (1768)

Other mineralogists noted that structure and hardness were one of the most valuable

[443] C. Huygens., *Traité de la Lumière*. Leiden, 1690, p. 95-6: "Tout cecy prouve donc que la composition du cristal est telle que nous avons dit. A quoy j'ajoute encore cette expérience; que si on passe un cousteau en raclant sur quelqu'une de ce surfaces naturelles, & que ce soit en descendant de Tangle obtus equilateral, c'est-à-dire de la pointe de la pinmide, on le trouve fort dur; mais en raclant du sens contraire on l'entame aisément Ce qui s'ensuit manifestement de la situation des petits spheroides; sur lesquels, dans la premiere manière, le cousteau glisse ; mais dans l'autre les prend par dessous, à peu près comme les écailles d'un poisson."

[444] P. Varignon., "Expériences sur la dureté des corps," *Anc. Mém. Paris*, **2**.; *ibid.*, "Conjecture sur la dureté des corps," *Anc. Mém. Paris*, **10**.

[445] C. Linneaus., *Systema Naturae*. Holmiae, 1768, **3**, p. 29-30. Linné's first statement on hardness apparently appeared in the *Amonenitates Academ.* (Holmiae, 1750).

[446] Bengt A. Quist., "Forsök på en del kisel arter och i synnerhet de hårdare så kallade äkta stenar," *Kongl. Svenska Wetenskaps Academiens Handlingar*, **39** (1768), p. 55-78.; German translation, "Versuch über einige Kiefelarten und besonders die härtern so genannten ächten Steine," *Abhandlungen aus der Naturlehre, Haushaltungskunst und Mechanik* (Kungl. Svenska Vetenskapsakademien), **1768**, p. 57-80.

[447] R. Kirwan., *Elements of Mineralogy*. London, 1784, p. 171-3.

[448] R. Kirwan., *Elements of Mineralogy*. Second edition. London, 1794, **1**, p. 38.

| Mineral | Hardness | Sp. Gr. |
|---|---|---|
| Diamond | 20-18 | 3.2-3.4 |
| Ruby | 17-16 | 3.5-4.2 |
| Sapphire | 17-16 | 3.8 |
| Topaz | 14-11 | 2.8-4.2 |
| Spinel | 13 | 3.4 |
| Emerald | 12 | 2.8 |
| Garnet | 12 | 4.4 |
| Rock Crystal | 11 | 2.6 |
| Quartz | 10 | 2.7 |
| Amethyst | 11 | 2.7 |
| Carnelian | 11 | 2.7 |
| Agate | 12 | 2.6 |
| Onyx | 12 | 2.6 |
| Opal | 10 | 2.6 |
| Tourmaline | 10 | — |
| Zeolite | 8 | 2.1 |
| Fluorite | 7 | — |
| Calcite | 6 | — |
| Gypsum | 5 | — |
| Chalk | 3 | — |

Kirwan's Scale Abridged (1784)

features to determine species, but they did not attempt to give more than a cursiory definition of the property. This view was followed in the writings by Johann Thaddäus Anton Peithner [1727-1798][449] and John Hill.[450] The famous French crystallographer Romé de l'Isle believed that the accurate determination of the three characteristics of cystallization, specific gravity, and hardness were sufficent to define a mineral species, but he never gives an explicit explanation as to how to determine the hardness of the minerals.[451] In 1779 Wallerius only differentiates by hardness saying they are either hard or soft but does believe the property to be caused by the crystalline structure.[452]

In 1780 Torbern Bergman writes that testing gems by their hardness is usual. He calls attention to the fact that gems are usually tested by hardness factors and rates them in order as diamond, ruby, sapphire, topaz, genuine hyacinth, and emerald. The following passage, typical of the period, is taken from his *Opuscula Physica et Chemica*.

> The species of gems is used to be determined by the hardness ; and by that quality particularly, together with the clearness, has their goodness been estimated. The spinellus is particularly worthy of observation, which is not only powdered by the sapphire, but even by the topaz ; as also the crysolith, which is broken down by the mountain crystal, the hardness of which seems rather to be owing to the degree of exsiccation than the proportion of ingredients. The analysis of spmellus, of crysolith, and other varieties, will sometimes illustrate the true connection ; otherwise, after the diamond, the first degree of hardness belongs to the ruby, the second to sapphire, third to topaz, next to which comes the genuine hyacinth, and fourth the emerald.[453]

This was essentially the prevailing view of the hardness property until 1774 when the renowned German mineralogist Abraham Gottlob Werner estimated the hardness of minerals by scratching specimens by using a standard set of tests.[454] Based on this test he differentated six categories that he describes in §169-§175 of his textbook.

> Diamond-Hard. Gives sparks when filed.
> Quartz-Hard.
> Feldspar-Hard.
> Semihard. Fluorite.
> Soft. Chalcopyrite.
> Very Soft. Gypsum.

Jean Claude de La Métherie in his *Théorie de la Terre* (1797) describes hardness.[455]

By 1801 and the publication of *Traité de Minéralogie* the distinction method first

[449] J.T.A. Peithner., *Erste Gründe der Bergwerkswissenschaften, zweite Abhandlung über die Mineralogie*. Prag, 1780.

[450] J. Hill., *Fossils Arranged according to their obvious characters*. London, 1771.

[451] J.B.L. Romé de l'Isle., *Cristallographie*. Second edition. Paris, 1783, **2**, p. 370.

[452] J.G. Wallerius., *Brevis introduetio in historiam litterariam mineralogicam*. Holmiae, 1779.

[453] T.O. Bergman., *Opuscula Physica et Chemica*, **2**, p. 104, Upsaliae, 1780 ("De Terra Gemmarum," p. 72-117). English translation, *Physical and Chemical Essays*, **2**, p. 107-8, London, 1784 ("Of the Earth of Gems.").

[454] Werner, *Von den äusserlichen Kennzeichen der Fossilien*, 1774, p. 244-252. [SEE ...]

[455] J.C. De la Métherie., *Théorie de la Terre*. Paris, 1797, **1**, p. 36-8. [GoogleBook]

given by Werner proved so useful that René Just Haüy included his own methods for determing hardness. Haüy is not clear as to what he means by hardness, however. He also used a file, but now includes his fingernail to test hardness. He divides hardess into four categories, which can be subdivided:

1. Substances which scratch quartz. Examples, Diamant, Corundum, Ruby, Sapphire.
2. Substances which scratch glass.
   a) Communément étincelantes. Examples, Quartz, Peridot, Idocrase, Euclase, Axinite.
   b) Quelque sois étincelantes. Examples, Prehnite, Sphene, Amphigene, Amphibole.
3. Substances which scratch calcite. Non étincelantes. Examples, Lazulite, Apatite, Harmotome.
4. Substances which do not scratch calcite. Non étincelantes. Examples, Talc, Gypsum, Mica.

This was a somewhat more reliable method to distinguish hardness between minerals. Haüy defined his hardness by saying that if one mineral was scratched by another than it had to be softer than the abrading mineral. Although the idea was sound the accuracy of the method was subject to wide variability. It was left for another researcher to build a useable tool for the inspection of hardness.

In Tome I. (p. 221) Haüy defines hardness in a vague way, and gives (pp. 268-71) in four groups the substances (i) which scratch quartz, (ii) which scratch glass, (iii) which scratch calcspar and (iv) which do not scratch the latter substance. In these lists he confines himself to substances usually termed stones. On p. 348 of Tome III. Haüy gives the following list of the usual metals in order of hardness: lead, tin, gold, silver, copper, platinum, iron or steel. Perhaps the only importance of Haüy's work for the theory of hardness lies in the fact that he appears to have first suggested the 'mutual scratchability ' of substances as a measure of their relative hardness.

To bring a precision to the use of this character in mineral determination, Friedrich Mohs outlined his scale of hardness, which perpetuates to this day his name in mineralogy. Published in the *Versuch einer Elementar-Methode zur naturhistorischen Bestimmung und Erkennung der Fossilien* of 1812, it is a scale of relative hardness between minerals, where each member of the scale scratches the preceeding one and is cut by all following members. It consists of only ten intervals, and its true value was the minerals Mohs selected were common species, available to students and professionals alike. Mohs championed his system in his many textbooks.

| Mineral | Hardness |
|---|---|
| Talc | 1 |
| Gypsum | 2 |
| Calcite | 3 |
| Fluorite | 4 |
| Apatite | 5 |
| Feldspar | 6 |
| Quartz | 7 |
| Topaz | 8 |
| Corundum | 9 |
| Diamond | 10 |

Mohs' Hardness Scale (1812)

Mohs scale was widely applied in practical minealogy due to easy to remember minerals, but it was hampered to be used in a true scientific manner for two reasons. Two circumstances impair its accuracy of other methods. Mohs did not take into account that the hardness of a mineral's surface and corners can be different for the same mineral, and sometimes for example it is possible to scratch a mineral with another specimen of the same mineral, which normally should not be possible. For example, Mica and Gypsum sometimes show this phenomena. The second problem with Mohs scale is that the distance between the species it uses in terms of relative hardness are not equal-distant. Diamond is for example, considerablly harder than corundum, quartz is much harder than feldspar, etc.

Mohs gave numbers to these classes and placed other bodies with decimal places between these numbers by testing the relative hardness of two nearly equally hard bodies by their resistance to a file and the comparative noise.

[ADD ILLUSTRATION OF HARDNESS CURVES.]

In 1813 Johann Heinrich Lorenz von Pansner [1777-1851] appears to be the first to define an absolute hardness of minerals.[456] In his investigation, Panser studied mineral hardness and specific density. Using a method where a needle made of steel, copper or lead was worked back and forth across a crystal surface until a scratch was seen he created four classes. By then measuring the minerals density, he attempted to create an analytical method for mineral determination based upon the two values of its hardness and density. It was a poorly executed investigation that received only passing interest from mineralogists. But it was a step towards measuring absolute hardness. Krutsch suggested the addition of tin and zinc needles to the method, but little attention was paid.[457]

L. Pansner in a pamphlet published in St Petersburg in 1813 seems to have been the first to adopt the plan of testing minerals, not by scratching them upon each other but by means of a series of diamond and metal points. Later in a memoir entitled : Systematische Anordnung der Mineralien in Klassen nach ihrer Härte, und Ordnungen nach Hirer vpecißsclwn Schwere, published in both Russian and German in the Mémoires de la Société Impériale des Naturalistes, T. v., pp. 179-243, Moscow, 1817, we find him classifying minerals as follows: (a) Adamanti-Charattomena (scratchable by a diamond, but not by a steel graver); (b) CJudybi-CJiarattomena (by a steel but not by a copper graver); (c) Chalco-Charattomena (by a copper but not by a lead graver); (d) Molybdo-Cliarattoniena (by a lead graver); (e) AcJtarattoinena (those whose hardness cannot be tested by scratching). These classes formed by relative hardness are again subdivided according as the specific gravity of the mineral is less than 1, less than 2 etc., into (0) Natantia, (1) Hydrobarea, (2) Dirhydrobarea, (3) Tri-hydrobarea etc., etc. Pp. 183-202 (erroneously paged 173) are occupied with a table of several hundred minerals thus classified, with the specific gravities to four places of decimals. The remainder of the memoir does not relate to hardness but to a classification of inorganic substances by other physical characteristics.[458]

The conception of relative hardness based upon the power of one body to scratch a second is evidently very unscientific. Huyghens had shown a century earlier that the hardness of a body varies with direction, and its power to scratch varies also with the nature of the edge and face. The latter fact was well brought out by a memoir of William Wollaston entitled: "On the Cutting Diamond," *Philosophical Transactions*, **1816**, p. 265-9. This memoir draws a distinction between cutting and scratching, which has been unfortunately lost sight of by later writers on hardness. Wollaston shows that the diamond irregularly tears the surface unless its natural edge, which is the intersection of two curved surfaces and thus a curved line, be so held that a tangent to it lies in the plane face of the material to be cut and is also the direction of motion of the diamond. The curved surfaces must also be held as nearly as possible equally inclined to the plane face. By paying attention to similar principles Wollaston succeeded in getting sapphire, ruby and rock crystal to cut glass for a short time with a clean fissure. It required a fissure of only 1/100 of an inch deep to produce a perfect fracture.

Breithaupt (1823) added two minerals to Mohs scale to try and make the increments more equal distant between the hardness numbers.[459] He put biotite mica between Gypsum (2) and Calcite (3) and added Scapolite between Apatite (5) and Feldspar (6). Breithaupt's efforts were never widely adopted, however. Various textbooks continued to list the 10 interval scale of Mohs. By 1836, in his *Vollständiges Handbuch der Mineralogie* he is one of the first mineralogists to employ a general definition of the property, applying it as

[456] J.H.L. Pansner., *Resultate der Untersuchungen über die Härte und specifische Schwere der Mineralien.* St. Petersburg, 1813, 33 p.

[457] Grailich and Pekárek, p. 417.

[458] Todhunter, p. ??.

[459] J.A.F. Breithaupt., *Vollständige Charakteristik des Mineral-Systems.* Dresden, 1823, lxxx, 292 p.

a general characteristic to mineral bodies.[460] Breithaupt's scale of hardness of 12 classes did not appear to have met with any wide acceptance.

In 1828, Naumann says that he thinks hardness should be the measure of the absolute cohesion of the mineral.[461]

Moritz Ludwig Frankenheim (1829, 1830, 1833) successfully used Panzer's methods of using different metal needles to gage a minerals hardness.[462] But unlike other investigators he measured the hardness in different directions across a crystal face. Apparently nobody since Huyghens originally made the observation had attempted to determine the hardness of a crystal across different directions of its surface.[463]

The first experimentalist to obtain results of value from this method was Frankenheim in his *De crystallorum coluvesione. Dissertatio Inaugural* (Bratislaviae, 1829). Its contents are, however, embodied and extended in the same author's later book *Die Lehre von der Cohäsion* (Breslau, 1835). Frankenheim's results were obtained by scratching with the metal needle held in the hand and judging relative hardness by the pressure and pull necessary to produce a scratch. He applied this method to test the relative hardness of crystalline surfaces in different directions. It cannot be said that such a method is capable of really great scientific accuracy, but we shall have occasion later to compare some of Frankenheim's results with those of other experimentalists.

Seebeck (1833) introduced a devise to consistently measure the hardness of minerals.[464] By the late 1800s, it accurately determined of hardness of minerals could be made by the use of an instrument called a sclerometer (Burchard, 2004). The mineral is placed on a movable carriage, with the surface to be tested upon the horizontal; this is brought into contact with a stell point (or diamond point), fixed to a support above. The weight needed to cause the point to scratch the minerals surface is then determined. This method is further complicated that on a single mineral face, it may have a different hardness depending on which direction the sclerometer is applied.

To this time, the hardness of a mineral largely depended on its elasticity, and depending on which direction the measurement was taken on a crystal could show a large variation in its value. Kyanite for example has very different values of hardness depending if the measurement is taken along or across a crystal. Approaches were invented to take the absolute hardness of minerals.

In 1850 Rudolph Franz wrote in Latin his ideas about determining a minerals hardness, *De Lapidum Duritate æmque Metiendi Nova Methodo Dissertatio.* It was also translated into German.[465] This is an important memoir that relates comparative hardness of crystals on different surfaces, and in different directions on the same surface, and contains the results of numerous careful observations (Burchard, 2004).

Franz defines the hardness of a mineral as follows:

> Mir scheint nämlich die Härte eines Minerals diejenige Kraft desselben zu seyn, welche seine Theilchen zusammenhaltend, dem Körper, der diese zusammenhangenden Theilchen trennen will, Widerstand leistet. [So far this might stand as a definition of cohesion.] Sie ist also diejenige Kraft des Minerals, welche das Eindringen eines Körpers in das Mineral verhindert, und zugleich der Fortbewegung einer in die Oberfläche eingedrückten Spitze sich entgegenstellt. Das Maasa dieser Widerstandskraft ist nun aber offenbar der Druck, welcher angewandt werden muss, um den Körper zum Eindringen m das Mineral zu bringen (S. 37).

It seems to me that this manner of determining hardness may really measure two

[460] Breithaupt., *Vollständiges Handbuch der Mineralogie.* Dresden und Leipzig, 1836.

[461] Naumann., *Lehrbuch der Mineralogie.* Berlin, 1828.

[462] M.L. Frankenheim., *De crystallorum cohaesione, dissertatio Inauguralis.* Bratislavlae, 1829. [A German translation appears in Baumgartner's und Ettingshausen's *Zeitschrift für Physik und Mathematik* (Wien), **6** (1841).]

[463] Huyghens., *Tractatus de Luinine.* Paris, 1690, p. 72.

[464] Seebeck., *Sklerometer.* Programm der Cöln Realgymnasiums, 1833.

[465] R. Franz., "Ueber die Härte der Mineralien und ein neues Verfahren dieselbe zu messen," *Annalen der Physik* (Poggendorffs), **80** (1850), p. 37-55.

different kinds of resistance, viz. the resistance to entry and the resistance to tearing after entry. Franz assumed that in measuring these resistances he was measuring one and the same property hardness. Interestingly, a criticism of Franz's methods on rather different grounds will be found on p. 39 and 48 of Hugueny's *Recherches Expérimentales tur la Dureté det Corps* (Paris, 1865).

In 1852, Gustav Adolf Kenngott [1818-1897] published his "Ueber ein bestimmtes Verhältniss zwischen dem Atomgewichte, der Härte und dem speeifischen Gewichte isomorpher Minerale."[466]

This memoir does not state particulars as to the manner in which the hardness of the various substances discussed has been determined. The author supposes his atoms to be liquid and spherical ; he states that they can or must be treated as liquid if they are to group themselves into molecules and as such into crystals (S. 104). As to the numerical results given in the memoir, I am unable to express any opinion as to their value, but the conclusions which the author draws from his chemical data appear to be summed up in the following paragraph which ocairs on S. 114-5, and which I content myself with citing:

Wenn die hier vorgeführten Beispiele zeigen, dass bei isomorphen Species, welche homolog zusammengesetzt sind, ein bestimmtes Verhältniss zwischen dem Atomgewicht, dem Atom- oder Molecül-Volumen, dem 8pecifi8chen Gewichte und der Härte vorhanden ist, so dass mit dem relativen apecifischen Gewichte in geradem, oder dem Atomvolamen in umgekehrtem Verhältnisse die Härte steigt und fallt, und bei gleichen gleich ist, während die Krystallgestalten wegen der übereinstimmenden Gruppirung übereinstimmend sind, weil die gleichgeordneten Atome der einen die Masse in einem dichteren Zustande enthalten als die Atome der anderen, so zeigen sie auch gleichzeitig, dass auf diese Differenzen der Härte und des relativen specifischen Gewichtes die Stellung in der elektrochemischen Reihe oder das elektrochemische Verhältniss der verbundenen Atome ohne Einfluss ist. Aus diesem Grunde habe ich die Atome in der elektrochemischen Reihenfolge vorangestellt, darunter die Verbindungen der ersten Ordnung und in denselben die höheren, wo es dergleichen gibt, und es wird daraas ersichtlich, dass nicht durch den stärkeren elektrochemischen Gegensatz die grössere Härte und das grössere relative specinsche Gewicht hervorgerufen sind.

Wilhelm J. Grailich and F. Pekárek (1854)[467] were two mineralogists that studied the hardness of minerals. Together they designed a sclerometer that would become widely accepted as the best design. Working off the principal of Seebeck, they created a stationary scratch point across which the sample was drawn. The design was manufactured by Voigt and Hochgesang for a price of 220 Marks (Burchard, 2004). This memoir opens with an interesting historical account of the various modes of classifying or measuring hardness (§ 410-21). The authors note how unscientific was the earlier use of the word 'hard' by palaeontologists and mineralogists, and then record the researches of some of the writers.

Q. Sella[468]

Through the earlier research it was known that the hardness of crystals, as determined with a sclerometer, is different on different crystal faces, and that the variation is related to the crystal symmetry. In 1865, Frédéric Hugueny gave a more precise definition of this property and introduced the distinction between normal and tangential cohesion.[469] In his scholarly doctoral thesis that describes his *Experimental Researches on the Hardness of Bodies*, the first 50 pages is given over to a good introductory history of the subject. This is followed by a definition of the hardness property, a description of the apparatus he used to test for it, a discussion of the places where errors are encountered, and a review of the results derived. Finally, Hugueny compares the

[466] G.A. Kenngott., "Ueber ein bestimmtes Verhältniss zwischen dem Atomgewichte, der Härte und dem speeifischen Gewichte isomorpher Minerale," *Jahrbuch der k.k. geologischen Reichsanstalt Jahrgang* (Wien), **4** (1852), no. 3, p. 104-116.

[467] W.J. Grailich and F. Pekárek., "Der Sklerometer, ein Apparat zur genaueren Messung der Härte der Krystalle," *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften. Mathematisch-Naturwissenschaftliche Classe* (Wien), **13** (1854), p. 410-436.

[468] Q. Sella., "??????," *Turiner Akad.*, (April, 1861), p. ??-??.

[469] F. Hugueny., *Recherches expérimentales sur la dureté des corps.* Paris and Strasbourg, Gauthier-Villars, 1865.

results of his research from various methods.

L. Sohncke (1869) in his deep investigation of halite describes his methods for determining the minerals hardness.[470]

The subject of hardness was thoroughly investigated by F.S. Exner in 1873 who describes the forms of hardness across the faces of many crystals in a series of curves of hardness in his monograph, *Ueber die Härte der Krystallflächen.*[471]

He showed that the variations in hardness observered in any crystal are dependent upon the cleavages. Faces not cut by cleavage planes have constant hardness in all directions, while faces intersected by planes of cleavage show mininum hardness parallel to the intersection with the cleavage plane and if the cleavages are of unequal ease the minimum hardness is parallel to the plane of easiest cleavage. So consistant was this relationship that Exner was able to express it algebraically. He obtained the measurements by determining the least amount of weight required to scratch a crystalline surface in different directions for each 10° or 15° from 0° to 180°, as determined by a sclerometer. These directions are laid out as radii from the center, and the length of each is made proportional to the weight fixed by experiment. These points are then connected, and a specific hardness diagram for the mineral determined.

J.W.A. Pfaff (1883)[472] determined hardness by boring his hardness point into the mineral face and measuring the number of rotations needed to indent the surface. Pfaff drew a diamond splinter of definite shape 100 times back and forth in one place, then shifted and repeated, widening the groove. The loss in weight of the crystal for the saure number of movements of the dianiond over the saure area and with a constant pressure serve as approximate values for hardness, i.e., hardness is inversely as the loss in weight. Pfaff also used a revolving diamond point. For equally deep Penetration the hardness was as the number of revolutions.

T. Turner (1886) used an apparatus similar to Franz's in which the mineral was fixed and scratched with a moving point.[473]

F. Auerbach (1891, 1892, 1896) attempted to create a scale of absolute hardness.[474] Following the definition of hardness given by Hertz, Auerbach devised a method in which a plano convex lens of any mineral is pressed against a horizontal plate of the same mineral. Both are bent and touch throughout a circuiar space, and for some pressure 1' the elastic limit is reached, at which there is produced, if the mineral is brittle, a circular fissure, or, if the mineral is tough, a circular permanent indentation.

According to Auerbach the limit pressure $P_1$ upon a square mm. of surface varies with the radius $r$ of the lens, but the product of $P_1$ into the cube root of this radius $r$ is essentially constant and may be called the Absolute Hardness, that is

$$H = P_1 \sqrt[3]{r}$$

On this basis he determines the absolute values of the Moh's scale to be: corundum, 1,150; topaz, 525; quartz, 308; orthoclase, 253; apatite, 237; fluorite, 110; calcite, 92; gypsum, 14.

A.K. Rosiwal (1893, 1894, 1896) [475] used a standard powder to grind the surface.

P. Jannetaz and M. Goldberg (1895) studied the effect of grinding as a test for

[470] L. Sohncke., "Halite," *Poggendorffs Annalen*, **137** (1869), p. 177.

[471] F.S. Exner., *Ueber die Härte der Krystallflächen.* Vienna, 1873. 166 p.

[472] J.W.A. Pfaff., "Mesosklerometer," *Sitzungsbericht bayern Akademie Wissenschaften, mathematik-physikalische Klasse* (München), **13** (1883), p. 55.

[473] T. Turner., " A new indentation test for determining the hardness metals," *Proceedings of the Birmingham Philosophical Society*, **5**, (1886), pt. 2, p. 240-??.

[474] F. Auerbach., *Wied. Ann.*, **43** (1891), p. 61, **45** (1892), p. 262, 277 & **58** (1896), p. 357. English translation of the first paper, "The absolute measurement of hardness," *Smithsonian Report*, 1891, p. 207-236. Translated by Carl Barus.

[475] A.K. Rosiwal., "Ueber eine neue Methode der Härtebestimmung durch Schleifen," *Anzeige* (Wien), **30** (1893), p. 104-105.; *ibid.*, "Ueber eine neue Methode der Härtebestimmung der Minerale, insbesondere jener des Diamanten," *Deutsch. Natf. Verh.*, Theil 2, pt. 1, (1894), p. 189-90.; *ibid.*, "Neue Untersuchungsergebnisse über die Härte von Mineralien und Gesteinen," *Jahrbuch k.k. geol. Reichsanstalt* (Wien), **17** (1896), p. 475-491.

hardness.[476] They employed a so-called, "Usometer," consisting of a rotating grinding disc, upon which four plates, the hardness of which is to be determined, were pressed by normally acting weights, the loss of weight of each giving the relative hardness.

T.A. Jaggar (1897) describes an instrument of his own design that he employed a micro-sclerometer of his own invention that in essence was a modification of Pfaffs technique.[477] However, by means of this instrument he was able to test the hardness of minerals present in thin sections under the microscope. Jaggar designed an attachment to the microscope, in which the point of a cleavage tetrahedron of diamond is rotated at a uniform rate and under uniform pressure until a cut of uniform depth is obtained (measured by focusing an the rulings of a Zeiss micrometer glass, which is slightly inclined and follows the downward movement of the diamond point). The number of rotations of the point varies as the resistance of the mineral to abrasion by diamond.

J.A. Brinell (1900) describes his experiments for establishing the relative degree of hardness of materials.[478] His test specimens are subjected to the pressure of a heavy weight, with a small sphere of steel interposed between the weight and test surface of the material. The impression left on the surface forms a tolerably indication of the degree of hardness possess by the objects tested. His tables show the relative hardness of many metals he tested in this method. are chiefly based on resistance to penetration.

In 1900 J.-R. Rydberg wrote on the hardness of simple bodies.[479] He represents the hardness of the elements as points on a curve, whose abscisse by the atomic weight and their ordinate are certain by the hardness of the element concerned. After run this curve belongs the hardness into that group of characteristics, with which the periodicity can be led back to a periodic function into the large one the cohesion. Here belong among other things density, expansion, atomic heat, melting point, heat of fusion, boiling point and most flexible characteristics of the raw materials.

Schroeder van der Kolk (1901)[480] gives a comprehensive look at the hardness property. He begins by comparing specific density and atomic weight before delving into the hardness property. He then gives a table of approximately 300 minerals with the first column containing the name of the mineral, the second the atomic or molecular weight, the third the specific gravity, the fourth the compaction, and the fifth the hardness by the Mohs scale.

Kip (1907, 1911)[481] outlined in two articles that invited a single definition of hardness, to establish a theoretical basis for the best method to investigate hardness and to put the method into practice by means of a suitable, standard apparatus and adequate mathematical calculation.

Holmquist (1911, 1914, 1916)[482] employed grinding techniques to determine the hardness of a wide range of minerals. His results with regard to the relative hardness of minerals agree closely with those determined by Rosiwal.

The method of Vickers is chiefly based on resistance to penetration (Vickers's method has been applied to the microscopic examination of polished sections since 1936). S.B. Talmage

[476] P. Jannettaz and M. Goldberg, "Dureté des matières vitreuses et cristallisées, déterminée au moyen de l'usomètre," *Ass. Franç. C.R.*, Part 2, **9** (Aug., 1895), p. 417-425.

[477] T.A. Jagger., "A microsclerometer for determining the hardness of minerals," *American Journal of Science*, 4th Series, **4** (1897), p. 399-412. [Contains a good bibliography of the subject.]

[478] J.A. Brinell., *Teknisk Tidskrift*, **30** (1900), p. 69-87, illus.

[479] J.-R. Rydberg., "Die Härte der einfachen Körper," *Zeitschrift für physikalische Chemie*, **33** (1900), p. 353-359.

[480] Schroeder van der Kolk., "Ueber Härte in Verland mit Spaltbarkeit," *Verh. d. Kon. Ak. v. Wet. te Amsterdam*, **8** (1901), 12 plates [Appeared 1902].

[481] H.Z. Kip., "Determination of the hardness of minerals," *American Journal of Science*, 4th Series, **27** (1907), p. 23-32 and **31** (1911) , p. 96-98.

[482] Holmquist. "Ueber den Relativen Abnutzungswiderstand der Mineralien der Härteskala," *Geologiska Föreningen i Stockholms Förhandlingar*, **38** (1911), p. 281.; *ibid.*, "Die Schleifhärte der Feldspathe," *Geologiska Föreningen i Stockholms Förhandlingar*, **36** (1914), p. 401.; *ibid.*, "Die Härtestufe," *Geologiska Föreningen i Stockholms Förhandlingar*, **38** (1916), p. 501.

(1926) has perfected the earlier sclerometer technique; P. Le Rolland's method (1926) is based on the influence of the hardness of a pendulum's knife edge on the duration of its oscillations.


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1865 Frédéric Hugueny., *Recherches experimentales sur la dureté des corps*. Paris and Strasbourg, Gauthier-Villars, 1865. vii, [1], 109 p., 6 plates.

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## 5.6 Optical Properties[483]

Transparent minerals, or those that become transparent when sliced extremely thin, show optical properties. A mineral that is transparent interacts with the rays of light that pass through it. Observing the characteristics of the light before and after it enters the mineral, and noting as well changes in the mineral itself, can lead to its identification. In the 19th and early 20th centuries, optical mineralogy became one of the most widely used tools of those available to mineralogists.

### 5.6.1 Double Refraction[484]

Double refraction (now termed *birefringence*) is the property of a crystalline substance to split a beam of light passing through it into two different rays. One of these rays is angularly offset from the other, resulting in two images being observed when a single image is viewed through the substance. If for example a line is viewed through a transparent crystal of calcite, it will appear double in every direction

[483] Further historical information may be found in: Jed Z. Buchwald., *The rise of the wave theory of light: Optical theory and experiment in the early nineteenth century*. Chicago, University of Chicago Press, 1989. xiv, 498 p., illus. [History of optics in the 18th and 19th century.; ISBN 0226078841.] • P.P. Ewald. , "Zur Begründung der Kristalloptik," *Annalen der Physik*, **359** (1917), no. 24, p. 557-597. • Edmund Hoppe., *Geschichte der Optik*. Leipzig, Verlagsbuchhandlung J.J. Weber, 1926. 262, [1] p., illus. [History of optics.; Reprinted, Wiesbaden, Dr. Martin Sandig oHG., 1967.] • Henry John Steffens., *The Development of Newtonian Optics in England*. New York, Science History Publications, 1977. viii, 190 p. [Surveys the evolution of the corpuscular theory of light from Newton to the work of David Brewster in the early 19th century.] • W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

[484] Further historical information may be found in: David Brewster., "Historical Account of its Discoveries respecting the Double Refraction and Polarisation of Light," *Edinburgh Philosophical Journal*, **1** (1819), p. 289-296, **2** (1820), p. 167-170, **3** (1820), p. 285-296, **4** (1821), p. 124-130, **8** (1823), p. 149-160, 245-256, **9** (1823), p. 148-152, **10** (1824), p. 90-96. • Jed Z. Buchwald., "Experimental investigations of double refraction from Huygens to Malus," *Archives Internationales d'Histoire des Sciences*, **21** (1979-80), p. 311-373. [Traces 18th-century attempts to determine experimentally a law of double refraction.] • *ibid.*, *The rise of the wave theory of light: Optical theory and experiment in the early nineteenth century*. Chicago, University of Chicago Press, 1989. xiv, 498 p., illus. [History of optics in the 18th and 19th century.; ISBN 0226078841.] • Burke, *Origins of the Science of Crystals*, 1966, p. 138-146. • André Chappert., *Etienne Louis Malus (1775-1812) et la théorie corpusculaire de la lumière. Traitement analytique de l'optique géométrique, polarisation de la lumière et tentative d'explication dynamique de la réflexion et de la réfraction*. Paris, Vrin, 1977. 283 p., illus. [Full discussion of Malus' theory of light.] • Mariano Colubi López., "Leyes físicas versus leyes experimentales: El intercambio de información entre Brewster y Biot acerca de la relación entre les leyes de doble refracción y las de polarización (1813-1819.)," *Llull: Boletin de la Sociedad Española de Historia de las Ciencias*, **21** (1998), p. 357-385. [History of double refraction and the role played by Biot and Brewster.] • Eugene Frankel., "The search for a corpuscular theory of double refraction: Malus, Laplace and the prize competition of 1808," *Centaurus: International Magazine of the History of Mathematics, Science, and Technology*, **18** (1974), p. 223-245. • Edgar W. Morse., *Natural philosophy, hypotheses, and impiety: Sir David Brewster confronts the undulatory theory of light*. Dissertation, University of California, Berkeley, 1972. 356 p. [Univ. Microfilms order no. 75-22448.] • Lars Gårding., "History of the mathematics of double refraction," *Archive for History of Exact Sciences*, **40** (1989), no. 4, p. 355-385. • Edmund Hoppe., *Geschichte der Optik*, 1926, p. 75-82. • *ibid.*, *Geschichte der Physik*, 1926, p. 259-261. • C. Klein., "Über das Krystallsystem des Apophyllits und den Einfluss des Drucks und der Wärme auf seine optischen Eigenschaften," *Sitzungsberichte der preussischen Akademie der Wissenschaften*, **1892**, pt. 1, p. 217-267. [Contains a long historical introduction of the optical studies done on apophyllite.] • C.M. Marx., "Zur Geschichte der Lehre von dem Doppelbrechung," *Annalen der Physik* (Poggendorff), **78** (1849), p. 272-276. • Vasco Ronchi., *The nature of light: An historical survey*. Cambridge, Mass., Harvard University Press, 1970. xii, 288 p., illus. (some colored), facsims., plates, portaits. [A history of optics.; ISBN 0435547526.] • W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

but one—that of the vertical axis of the rhombohedron. One image is created by the ordinary refraction of light, while the other, by an extraordinary refraction. If the same crystal is placed over a point, and turned around, one image will appear to revolve around the other. The direction in which there is no refraction is called the *axis of double refraction*, or *neutral line*, since in its direction the ordinary and extraordinary rays coincide. Double refraction increases in passing from this direction to one at right angles with it. When there are two axes of double refraction, both rays are due to extraordinary refraction. The two axes are in a vertical plane in right prisms, but not so in oblique prisms. The angle between these axes has been determined for many minerals, and has served to distinguish species, which is the basis for optical mineralogy.

The property was first reported in 1669 by Erasmus Bartholin [1625-1698] when he published a small book about his discovery, *Experimenta Crystalli Islandici Disdiaclastici*, in which he describes his observations and experiments he made concerning Iceland spar (a clear variety of calcite).[485] Christiaan Huygens [1629-1695] offered an explanation of the property in terms of his wave theory of light. Interestingly from the experiments described in this work it is clear that Huygens observing the interaction of two rhombohedral calcite crystals was on the threshold of the discovery of polarization; however, he stopped short there because polarization seemed to be irreconcilable with the theory that light waves were analogous to (longitudinal) sound waves. This was published in his important 1690 study, *Tractatus de Lumine*.[486] Through his experiments Huygens discovered that quartz also possessed the property, the only other mineral besides calcite known to possess the property until Haüy made a specific study of the subject.

Isaac Newton [1643-1727] experimented with minerals. He calculated the thickness of the thinnest plates of mica and gypsum, and from his experiments with the double refraction property of Iceland spar he advanced theory of light that consisted of waves and insisted that it was corpuscular in nature.[487] He conceptualized light rays with four sides or "quarters," which he though might be endowed with forces exhibiting polarity, similar to magnetic forces. Two of these, he thought, had the property of usual refraction, while the other two had unusual refraction (double refraction). He believed the unusual refraction exhibited by Iceland spar was created by an attraction between the light rays and particles inside the crystal.

The French physicist Charles-François De Cisternai Du Fay [1698-1739] studied the properties of various substances, including crystals. He is now credited as the original discoverer of the interrelation between crystalline form and the phenomenon of double refraction, although his priorty was not recognized for a very long time after his death.[488] Du Fay died tragically young, but among the last papers he was working on was his examination of the property of double refraction on which he conducted a great number of exact measurements. Among the general principles he deduced from his observations was that all transparent stones that have right angles are only singly refracting, whereas crystals whose angles are not right angles are doubly refracting and that the amount of the double refraction is dependent upon the inclination of these angles. Unfortunately this work was never formally published in a scholarly journal. Instead the only knowledge we have of it is from Du Fay's éloge written by De Fontenelle, at that time secrétaire perpétuel of the Academie, and recorded in the *Histoire de l'Academie Royale des Sciences* (1739, p. 73-83, Paris, 1741.)[489] From De Fontenelle's description of the work it is clear he had before him some

[485] E. Bartholin., *Experimenta Crystalli Islandici Disdiaclastici*. Hafniae, 1669.

[486] C. Huygens., *Tractatus de Lumine*. 1690.

[487] I. Newton., *Opticks*. London, 1730, p. 373.

[488] Carl Michael Marx., "Zur Geschichte der Lehre von dem Doppelbrechung," *Annalen der Physik* (Poggendorff), **154** (1849), no. 10, p. 272-275.

[489] Hoppe, *Geschichte der Physik*, 1926, p. 260. • Adolf Pabst., "Charles-François du Fay, a pioneer in crystal optics," *American Mineralogist*, **17**, p. 569-572.

unfinished manuscript or notes that are now lost. Sadly, Du Fay's contribution, probably because of the unorthodox manner in which it was recorded, never was picked up by later researchers or most historians of science.[490] If it had, the development of the science of crystallography would probably have been advanced considerablly, because it was nearly 80 years before the same observations were again made.

In 1762 Giovanni Battista Beccaria [1716-1781] published his observations on the property of double refraction exhibited by quartz.[491] He noticed that the edges of the crystal showed a wide range of colors, but he did not give an explanation for the feature.

Unlike amorphous material, the molecular arrangement inside a crystal causes the development of double refraction which was dramatically shown by the discoveries of the Abbé Alexis Marie de Rochon [1741-1817]. He demonstrated that if a glass plate is attached to various faces of quartz plates double refraction develops.[492] He is credited later with inventing an insturment called the "micrometer," which was developed as an attachment to a telescope.[493] Its optics utilized two precisely cut quartz prisms that create achromatic prisms that used the double refraction of the material to produce two images that were made to coincide by moving one optical element along a scale.

In his crystallographic studies of minerals, René Just Haüy [1743-1822] naturally considered the phenomena of double refraction. He accepted the outline of Newton's explanation of double refraction, but he was hessitant to give any hypothesis that related the phenomenon to the internal structure based on the integrant molecule.[494] In his research he always attempted to match the duplicate images of the objects seen through the crystal to the sides of the integrant molecules he theorized existed inside the crystal. In this way he studied the crystals of calcite, rock crystal, sulfur, barite, and gypsum. Although he noticed that the absence of double refraction was related to an axial direction of the primitive forms of these substances, he did not notice the optical biaxiality of the last three minerals.

Haüy in his *Traité de Minéralogie* (1801) gives a list of the double-refracting minerals, obtained as a result his own searches, and for the first time isolates the optically isotropic crystals, which do not exhibit the double-refracting property.[495] But his experimental method, observing the image of a pin through prisms constructed of the mineral material to see if its image doubled could not lead to satisfactory results. Different orientations of the needle observed from different distances caused Haüy to miss the weak double refract shown by some minerals, or mistake a strong simple refraction for the property. This all leads to the fact that the list of Haüy, which contains 20 "double refracting" and even 10 "single refracting" minerals is built from erroneous data. For instance, among the single refracting minerals that he correctly recognized, namely fluorite, spinel, garnet, sphalerite, he adds apatite, tourmaline, and axinite. At the same time, he does not include diamond or rock salt (halite) to the list, although in their descriptions they are noted as belonging with minerals that exhibit single refraction. In spite of these omissions of Hauy, he accumulated enough evidence

[490] Only Hoppe in his history of physics mentions Du Fay's investigations of crystal optics, *Geschichte der Physik*, 1926, p. 260.

[491] G.B. Beccaria., "Observation sur la double réfraction du cristal de roche," *Journal de Physique*, **2** (1762), p. 504-510. English translation, "An Account of the Double Refractions in Crystals," *Philosophical Transactions*, **52** (1683-1775), p. 486-490. • Hoppe, *Geschichte der Optik*, 1926, p. 75.

[492] A.M.de Rochon., *Recueil de Mémoires sur la Mécanique et sur la Physique.* Paris, Barrois l'ainé, 1783. xiv, [2], 384, xxxij p., 10 plates (including diagrams). [Citation from Hoppe, *Geschichte der Optik*, 1926, p. 75-76.]

[493] A.M.de Rochon., *Mémoire sur le micromètre de cristal de roche pour la mesure des distances et des grandeurs. Avec une instruction de M. Torelli-de-Narci sur la manière de se servir de la lunette contenant un micromètre fait avec des prismes de cristal de roche.* Paris, A. Beraud, 1807. 62 p., one table.

[494] R.J. Haüy., "Sur la double réfraction du spath calcaire transparent," *Journal d'Histoire Naturelle*, **1** (1792), 63, 158-160; "Sur la double réfraction du cristal de roche," *Journal d'Histoire Naturelle*, **1** (1792), p. 406-408; "Sur la double réfraction de plusiers substances minérales," *Annales de Chimie et de Physique*, **17** (1793), p. 140-156.

[495] R.J. Haüy., *Traité de Minéralogie*, **1**, p. 237.

to establish rules based according to his theory of the integrant molecule that species characterized by high degree of symmetry, possess simple refraction. Thus forms of the cube, octahedron, or those possessing cubic symmetry do not show double refraction. He also attempted to distinguish between singly and doubly refracting crystals and had correlated the optical property with minerals containing certain highly symmetrical molécule intégrantes. In other words, Haüy observed that the optically isotropic crystals must belong to one group, now recognized as the cubic (centered) symmetry [?? CHECK THIS ??]. Moreover, in double refracting bodies he established that the directions, along which the double refraction is not revealed, are planes where the highest symmetry occur. Understanding the importance of determining the optical properties of minerals, Haüy proposed using them in a practical way for distinguishing between faceted precious stones, which could not be easily tested by other destructive methods. Later, this idea would lead to the development of a new insturment called the refractometer (see §14.6.2.).

In 1881, Richard Tetley Glazebrook [1854-1935] examined Iceland spar and its interaction with light, particularly the creation of double refraction and dispersion.[496] Charles Sheldon Hastings [1849-1932] published an improvement on Glazebrook's study in 1888.[497]

### 5.6.2 Basis of Optical Mineralogy[498]

**REWORK:** In 1807 Johann Jacob Bernhardi [1774-1850] emphasized that double refraction was intertwinned with the crystal's internal structure.[499] He pointed out that double refraction appeared only in irregularly crystallized bodies, which although found in different degrees in various materials, it followed the same rules in all. Examining crystals of calcite, quartz, emerald, and beryl, which are uniaxial, as well as zircon, vesuvianite, and natrolite, which are biaxial, Bernhardi must actually have observed the optical biaxiality in these later crystals, although he did not recognize its importance. He does emphasize, however, that double refraction was dependent upon the internal structure of the crystal and that there was an axis of refraction about which the phenomena occurred.

The connection between optical properties and crystalline form occurred only after the discovery in 1809 of the polarization of light by reflection by Etienne Malus [1775-1812].[500] Working in the framework of the integrant molecule, Malus suggested that symmetry of the molecules was the principal element to create the phenomena of double refraction. He constructed a variety of instruments for the study of polarization both by reflection and double refraction. From his experimentaions of different crystals he showed that two refracted rays are respectively polarized in planes perpendicular to each other. He also found that in simple refraction, the ratio between the sines of the angles of incidence and refraction was a constant quantity, but this relationship was variable in the case of the extraordinary ray. This suggested that it depended not only upon the inclination of the incident ray upon the refracting surface but also upon its position relative to the axis of the integrant molecule of the crystal. The emergent ordinary and extraordinary rays had the same direction when the incident ray fell upon a face that was parallel or perpendicular to the

[496] R.T. Glazebrook., "Double Refraction and Dispersion in Iceland Spar: An Experimental Investigation, with a Comparison with Huyghen's Construction for the Extraordinary Wave," *Transactions of the Philosophical Society of London*, **171** (1881), p. 421-449.

[497] C.S. Hastings., "Law of double refraction in Iceland spar," *American Journal of Science*, 4th series, **35** (1888), p. 68-81.

[498] Further historical information may be found in: Jed Z. Buchwald., *The rise of the wave theory of light: Optical theory and experiment in the early nineteenth century*. Chicago, University of Chicago Press, 1989. xiv, 498 p., illus. [History of optics in the 18th and 19th century.; ISBN 0226078841.] • Burke, *Origins of the Science of Crystals*, 1966, p. 138-144. • Shafranovskii, *Istoriia kristallografii XIX vek*, 1980, p. 78-95.

[499] J. Bernhardi, "Beobachtung über die doppelte Strahlenbrechung einiger Körper, nebst einigen Gedanken über die allgemeine Theorie derselben," *Journal für die Chemie und Physik von A. F. Gehlen*, **4** (1807), p. 230-258.

[500] E. Malus, "Sur une propriété de la lumière réfléchie," *Mémoires de Physique et de Chimie de la Société d'Arcueil*, **2** (1809), p. 143-158; and "Sur une propriété des forces répulsives qui agissent sur la lumière," *Mémoires de Physique et de Chimie de la Société d'Arcueil*, **2** (1809), p. 254-267.

axis of the crystal and emerged from a face parallel to the incident face. In Malus' view this attribute gave a direct means to determine the axis of refraction in a wide variety of crystalline materials. If an image was not doubled, when viewed across two parallel faces, the conclusion was that these faces were either parallel or perpendicular to the axis of the crystal. In the rhombohedron, the axis of refraction was the same as the crystal axis, but there was not sufficient information available, according to Malus, to state that this was the case a priori in other crystal forms.[501] Thus Malus, who had studied Bernhardi's work, failed in the same way to distinguish uniaxial and biaxial crystals.

In 1811 Dominique François Arago [1786-1853] observed the rich colors produced by polarized light passing through thin plates of certain crystals thus establishing a valuable and sensitive method to detect double refraction in minerals. He discovered these "interference colors" by placing a sheet of mica between a glass reflector and a calcite prism. One can only imagine the impression that the striking colors must have made on him.[502] He also observed that the colors remained stable if the glass reflector was replaced by the sky. This gave strong evidence that the blue sky must be polarized. He presented his preliminary results in a paper read the Paris Academy, and thereafter helped develop a new wave theory of light that could accurately explain these observations, which were unexplained by contemporary theories.

In 1812 David Brewster [1781-1868] and Jean Baptiste Biot [1774-1862] independently realized that the interference colors that were observed when light passed through thin plates of doubly refracting crystals were also weak indications of the materials double refracting property. Brewster had experimented with topaz (orthorhombic), while Biot had worked with a variety of mica (monoclinic). Continuing their respective researches, both Brewster and Biot arrived at the concept of optical biaxiality, but Biot, in a long paper, was the first to report his results.[503] A short time later Biot also determined that uniaxial crystals could be divided into two classes. He assumed that the polarized light corpuscles in the extraordinary ray in quartz were attracted to the vertical axis whereas those in beryl were repelled from it, pointing out that the Iceland spar had "beryl" polarization.[504] Brewster rejected Biot's theory of attractive and repulsive forces, however, insisting instead that the different classes arose because of the internal structure of the crystal.

> In crystals ... the polarizing structure ... must therefore depend on the form of their integrant molecules, and the variation in their density. ... When these crystals have a spherical form diminishing in density towards an axis, and have these axes arranged by laws of crystallization, they will constitute a crystal of the positive class, ... quartz. ... When the density of the spheres increases towards their axes, their symmetrical combinations will constitute a crystal of the negative class, such as beryl.[505]

Thus, Biot's terminology of differences resulting from attractive and repulsive forces was replaced with Brewster's that explained a crystal as being either optically positive or negative.

Both scientists, however, quickly pointed out that the crystal axes of many substances corresponded with the axes of double refraction. Biot suggested that the axis of double refraction proved that a crystal was an aggregate of atomic elements arranged in a symmetrical structure around the axis.[506] Asymmetry

[501] E. Malus., *Théorie de la double réfraction de la lumière dans les substances cristalisées*. Paris, 1810, p. 95, 177.

[502] Shafranovskii, *Istoriia kristallografii XIX vek*, 1980, p. 80.

[503] J.B. Biot., "Mémoire sur un nouveau genre d'oscillation que les molécules de la lumière éprouvent en traversent certains cristaux," *Mémoires de l'Institut* (1812), Part I, p. 1-371; David Brewster, "On the Affections of Light Transmitted through Crystallized Bodies," *Philosophical Transactions of the Royal Society of London*, (1812), Part I, p. 187-218.

[504] J.B. Biot., "Sur le découverte d'une propriété nouvelle dont jouissent les forces polarisent des certains cristaux," *Mémoires de l'Institut* (1812), Part I, p. 19-30; and "Observations sur la nature des forces qui partagent les rayons lumineux dans les cristaux doués de la double réfraction," *Mémoires de l'Institut* (1813-1815), p. 221-234.

[505] D. Brewster., "On the Laws of Polarization and Double Refraction in Regularly Crystallized Bodies," *Philosophical Transactions of the Royal Society of London*, **1818**, p. 264.

[506] J. B. Biot, "Mémoire sur l'utilité des lois de la polarisation de la lumière, pour reconnaître l'état de

was demonstrated by the fact that a light ray incident on the crystal in an oblique direction to this axis was doubly refracted. He emphasized that double refraction would be useful as an experimental index to analyze crystalline substances in an effort to determine the system of crystallization, particularly where the exterior form was not a sufficient indication of the interior crystalline state.

During his research, Brewster classified almost three hundred crystalline materials according to whether they had one, two, or three axes of double refraction, or, in modern terms, whether they were uniaxial, biaxial, or optically isotropic, respectively. He pointed out that all crystals having the cube, the regular octahedron, or the rhombic dodecahedron as primitive forms have three axes of double refraction. Hence, in these crystals, no double refraction is evident. All crystals having the rhombohedron, the hexagonal prism, or the octahedron with isosceles triangular surfaces as primitive forms have one axis of double refraction. Substances with two axes of double refraction crystallize in other irregular forms. Hence, according to Brewster, the phenomenon of double refraction demonstrated the position of the crystal axes and could be used to determine the correct primitive forms of crystals. Brewster believed it was much more difficult to gain knowledge of the primitive form by cleavage and calculation than it was to test a crystal for double refraction. In Brewster's opinion, tungstate of lime (Scheelite, $CaWO_4$) provided a good example of the utility of this optical phenomenon in the derivation of the primitive form. Haüy believed that the form of the integrant molecule of this substance was a cube, but since it was doubly refracting, this geometry was impossible according to Hauy's model, and was accordingly changed.

In 1818 all of these results were compiled by Brewster in his important paper, *On the Laws of Polarization and Double Refraction in Regularly Crystallized Bodies*.[507] He explains in it the connection between the optical characteristics and the 'primitive form' of a crystal. He also introduced a satisfactory correlation between the form and optical properties of isotropic and anisotropic crystals, though not completely for biaxial substances. Extending his research, Brewster became bolder in his assertation of the connection of the crystalline form and the optical properties. He named 11 minerals that based on their optical properties could not possess the primitive form assigned to them by Haüy. By 1823, 8 of these minerals had been assigned new forms to conform with his observations. For example, boracite could not have a cubic integrant molecule because it was doubly refracting; therefore, it must have some other form.[508]

John Frederick William Herschel [1792-1871] published in 1820 a paper on the interaction of homogeneous light with crystallized bodies that brought substantial progress to the knowledge of the optical characteristics of crystals.[509] During experimental inquiries on the polarization of light, he was struck by the very considerable number of deviations in the colors of their lamina, first observed by Newton, and which many crystals exhibit when cut into plates perpendicular to one of their axes. His curiosity was excited and he began an inquiry into the cause of what produced them, especially since their appearance was a problem for Biot's theory. He determined they were caused by "axes of birefringence" that caused the behavior of light to be connected to the symmetry axis of the mineral crystal. To show that the colors produced were not created by the color of light transmitted through the crystal, Herschel uses colored glass to filter the

cristallisation et de combinaison dans un grand nombre de cas où le système cristallin n'est pas immédiatement observable," *Mémoires de l'Académie Royale des Sciences*, **1816**, p. 275-346.

[507] D. Brewster., "On the Laws of Polarization and Double Refraction in Regularly Crystallized Bodies", *Philosophical Transactions of the Royal Society of London*, **1818**, p. 199-273.

[508] David Brewster, "Reply to Mr. Brooke's Observations on the Connexion between the Optical Structure of Minerals and Their Primitive Forms," *Edinburgh Philosophical Journal*, **9** (1823), p. 361.

[509] J.F.W. Herschel., "On the Action of Crystallized Bodies on Homogeneous Light, and on the Causes of the Deviation from Newton's Scale in the Tints Which Many of Them Develope on Exposure to a Polarized Ray.," *Philosophical Transactions of the Royal Society of London*, **1820**, I, p. 45-100.

light that passed through the crystal plates. In the mean time, Brewster had observed the same phenomena, which he mentioned in a paper he read before the Royal Society in 1818, but he had not attempted an explanation.

The foundations for correlation of the optical properties of crystals with their form or symmetry were thus in place by the second decade of the 19th century. Further research accumulated a mountain of evidence that supported the concept that crystals possessed in a unique axes of symmetry. In 1824 Eilhardt Mitscherlich [1794-1863] published a memoir describing the effects of temperature change on the dimensions of a number of crystals of various substances.[510] First, he demonstrated that crystals that were regular geometric solids, like the cube, the regular octahedron, and the rhombic dodecahedron, expanded uniformly in all directions upon a temperature increase and evidenced no change in the value of their interfacial angles. Second, crystals having rhombohedra or hexagonal prisms for their primitive forms displayed unequal expansion in one direction when they were heated. For example, calcite expanded nonuniformly in the direction of its vertical axis, whereas its expansion was uniform in the other two axial directions. Hence, crystals with one axis of double refraction reacted in exactly the same manner to heat as to light. Third, all crystals shown to possess two axes of double refraction expanded unequally in all three directions when heated. Mitscherlich concluded from his experiments that the expansion of crystals upon heating was related to the axes of crystallization and that these axes corresponded with the optical axes.

Haüy recognized the value of the phenomenon of double refraction in the identification of the integrant molecule of a substance, and he was willing to seek a new primitive form if this optical property indicated its absolute necessity. Further, he believed that, together with form, hardness, and specific weight, double refraction provided evidence of specificity, meaning that mineral species could be determined from them. But he did not ascribe to this directional property the importance other scientists attached to it. In fact just as isomorphism and dimorphism showed that the integrant molecule was not specific to a chemical compound, optical properties showed that the primitive form and integrant molecule could not accurately determined by cleavage of the secondary forms. Obviously, either Haüy's system must be entirely revised by the determination of the correct primitive forms, or another system of crystal analysis should be adopted.

Not all mineralogists, however, were prepared to attach such importance to optical characters as means of determining mineral species. Cases of apparent conflict between determinations made on the basis of chemical composition and crystallographic characters on the one hand, and optical characters on the other, soon arose. For example, Brewster, on optical grounds, regarded tesselite as a species distinct from apophyllite, in spite of the fact that Berzelius had shown the two to be identical in chemical composition. He also found that sulphato-tricarbonate of lead (leadhillite) was optically biaxial, whereas it was generally believed at that time to be a rhombohedral mineral. In the case of apophyllite, of course, Brewster was misled by the optically anomalous character of the mineral; but in the case of the leadhillite it was the optical determination that was correct, the mineral being really monoclinic but with a close approach to rhombohedral symmetry.

But the standard works on mineralogy of that time, and for many years later, contained no account of the optical characters, beyond reference to such features as the double refraction of calcite, the play of color (dispersion) of diamond, the dichroism of tourmaline, and, perhaps, the statement that the mineral had "simple" or "double" refraction, as the case might be. Many mineralogists recognized, however, that a knowledge of the optical characters would be of the greatest aid in determining minerals. Thus Jameson, in his *Manual of Mineralogy* (1821) says:

[510] E. Mitscherlich., "Ueber das Verhältnis der Form der kristalliserten Körper zur Ausdehnung die Wärme," in: A. Mitscherlich., *Gesammelte Schriften von Eilhard Mitscherlich.* Berlin, 1896, p. 195.

"To Dr. Brewster, mineralogists are indebted for a great discovery, namely, the number and position of the axes of double refraction of minerals. By means of this character we are enabled to determine mineral species; and even in those cases where neither form nor cleavage are present, to refer the mineral to its system of crystallization. We have no hesitation in considering it as a more certain and useful aid to mineralogists than chemical analysis. It ought to be introduced into all systems of mineralogy".[511]

Augustin Jean Fresnel [1788-1827] building on previous experimental work extended the wave theory of light to a large class of optical phenomena. By the year 1821, he was able to demonstrate through mathematical methods that polarization could be explained only if light was entirely transverse, with no longitudinal vibration whatsoever. Other optical phenomena were also given explanation. For example, through his wave theory he conclusively accounted for the phenomena of interference when light rays collide. Although Fresnel's wave theory of light had many converts, even from the most ardent of those previously believing in the corpuscular theory, his assertion that light is a transverse wave was a step too far for most. However, Fresnel stunned his critics when he next showed through an incredible deduction that double refraction could be deduced from the transverse wave hypothesis.[512] This was an important development for optical mineralogy, because it offered a brilliant explanation of the correlation between the observed optical properties and structural crystal form of many minerals. Essentially, Fresnel stated that when there are two axes of double refraction, both rays are due to extraordinary refraction. The two axes are in a vertical plane in right prisms, but not so in oblique prisms. Thus in biaxal crystals there is no spherical wave, since there is no single direction round which such crystals are symmetrical. But when there is an angle between these axes it could be measured for many minerals, and would in the 19th century be determined for many species that would serve as a specific characteristic to distinguish species.

After Fresnel's tragically young death his wave theory as it applied to crystal optics was further extended by the German crystallographer and physicist Franz Ernst Neumann [1798-1895].[513] Brewster had previously shown the interrelation between the optical properties and geometries of the crystals of the three crystallographic systems of the lowest category, but the crystal classes containing the rhombic, monoclinic and triclinic required further examination. To this question a significant role was played by Neumann's article on "the Thermal, Optical and Crystallographic Axes in the Crystalline System of Gypsum" (1833).[514] In it he explores the law of double refraction in the mineral gypsum from the point of view of Fresnel's mechanics and concludes that there was a correlation between the crystallographic forms axes, the axes of elasticity and thus the thermal and pressure axes. In this way the the interrelation between the strucutural form and the physical properties of a crystal of the rhombic system are for the first time clearly stated.

Neumann then turned his attention to exploring the optical properties of species in the monoclinic and triclinic crystal systems. He thought it was entirely possible that the phyisical properties of crystals always conform to the symmetry of the crystal. This position was supported by the research made by J. Herschel [xxxx-xxxx] and J.G. Nörrenberg [xxxx-xxxx] , who investigated the optical property of the crystals of monoclinic borax with the aid of the red and dark-blue glass. Neumann generalized their data, after adding to it his observations about gypsum and came to the conclusion that for the monoclinic crystals the axis of Fresnel's ellipsoid in the differently colored light rays changes not only its value, but also its orientation relative to crystallographic axes. This showed that in the monoclinic crystals

[511] R. Jameson., *Manual of Mineralogy*. London, 1821, p. ???.

[512] A.J. Fresnel., "Memoire sur la Double Refraction," 1827.

[513] Shafranovskii, *Istoriia kristallografii XIX vek*, 1980, p. 90-92.

[514] F.E. Neumann., "Die thermischen, optischen und crystallographischen Axen des Crystallsystems des Gypses," *Annalen der Physik* (Poggendorff), **27** (1833), p. 240-274.

the optical geometry is relative to the single plane which is symmetrical to its geometric form. This suggested that the optical axes of a crystal must lie either in the plane of symmetry, or in one of the planes perpendicular to it. In 1835, Neumann in a small paper noted that the absence of the symmetry regularities between the orientation of the optical ellipsoid and elements of the crystallographic structure in triclinic crystals.[515] These facts explained the question about the interrelations between the optical and geometric properties of the crystals of all seven systems.

The optical study of crystals was greatly facilitated when the physicist William Nicol [1768-1851], in 1828, invented the polarizing prism which bears his name, but for many years yet mineralogists were slow to avail themselves of optical characters as an important means of identifying minerals. Even in the third edition of Dana's *System of Mineralogy* (1850), when the chemical classification of minerals was adopted, the descriptions of minerals do not include any optical characters, except that the refractive index is given for diamond and possibly for one or two other species. There is, however, an introductory chapter, "Characters Depending on Light," in which a number of minerals are listed with their mean refractive index (for four of them, two indices are given), and in another table some twenty minerals are listed with their optic axial angle.

It was not until well after the middle of the 19th century that mineralogists began to make important use of optical characters, apart from color and lustre, in the determination of minerals, and this in spite of the fact that observation and study of the peculiar behaviour of light in its passage through crystals had much influence on the development of the science of optics.

In 1849, Henry Clifton Sorby [1826-1918] demonstrated the possibility of determining the minerals in rocks by the examination of thin sections under the polarizing microscope. From this time onward, however, study of the optical characters of minerals assumed increasing importance. Sorby's pioneering work in this field, and particularly the paper he published in 1857, on the microscopical structure of crystals, not only laid the foundations of microscopical petrology but at the same time raised optical mineralogy to a position of the first importance as a means of identifying minerals rapidly, even when in the smallest grains. Thereafter, a knowledge of the optical characters, at least of the minerals occurring in rocks, became imperative. Optical studies were being constantly refined and advanced, and one of Sorby's last papers describes a method for determining refractive indices.[516] The method he describes is identical in principle, though worked out in far greater detail, with that given by the Due de Chaulnes in 1767 for singly-refracting substances, although the method was devised quite independently.

From the outset, Alfred-Louis-Olivier Legrand des Cloizeaux [1817-1897] was one of the most active in this field, and his *Manuel de Mineralogie*, the first volume of which appeared in 1862, is remarkable for the immense amount of new information presented relating to the optical characters of minerals. He improved upon the clumsy microscopes of Amici and of Norrenberg, and examined the optical properties of 468 minerals and salts between 1857 and 1869.

Friedrich Eduard Reusch [1812-1891] in 1867 wrote on the reflection and refraction of the light at spherical surfaces under a condition of finite angles of incidence.[517]

Remarkable advances were made from that time forward. Microscopes and other optical instruments have been continually improved, a great variety of ingenious accessories have been invented, and new and more accurate, or more rapid, methods of operation have been devised. This made possible the examination of crystals

[515] F.E. Neumann., "Nachträgliche Beobachtungen in Betreff der optischen Eigenschaften hemiprismatischer Crystalle," *Annalen der Physik* (Poggendorff), **35** (1835), p. 203-205.

[516] H.C. Sorby., "On a New Method for Studying the Optical Properties of Crystals," *Mineralogical Magazine*, **15** (July, 1909), no. 70, p. 189-215.

[517] E. Reusch., "Reflexion und Brechung des Lichts an sphärischen Flächen unter Voraussetzung endlicher Einfallswinkel," *Annalen der Physik (Poggendorff)*, **206** (1867), p. 497-517.; *ibid.*, "Ueber die Körnerprobe am zweiachsigen Glimmer," *Annalen der Physik (Poggendorff)*, **136** (1868), p. 130-135, 632-634.

under the microscope in plane-polarized light, a field of research in which the petrologists were particularly active.

At the end of the 19th century, several excellent treatises on optical mineralogy by Americans appeared, namely, those by Luquer, Iddings and Johannsen.

In 1908 N.H. Winchell [xxxx-xxxx] and Alexander N. Winchell [xxxx-xxxx] published their *Elements of Optical Mineralogy, An Introduction to Microscopic Petrography.*[518] According to the authors, none of these contains a concise and clear exposition of the principles, methods and data of optical mineralogy. It is to supply this want that this text was written. The book is divided into three parts, as follows: (1) Principles and Methods, (2) Description of Minerals and (3) Analytical Tables. It covers the phenomena of light, the elements of mineralogy, and the application of polarized light to crystalline substances. Part two contains a systematic description of all the rock-forming minerals concerning which there is sufficient data to permit their being determined by means of the microscope. Part three is made up of exhaustive analytical tables for determination, microscopically, of rock-forming minerals.

### 5.6.3 Rotatory Polarization[519]

**REWORK:** The discovery of the rotation of the plane of polarization of light travelling through quartz was made by Arago in 1811. In 1812, Biot observed that quartz had the property of rotating the plane of polarization of transmitted light, but as an adherent of the corpuscular theory of light he found it impossible to offer a reason able explanation of his discovery. (Fresnel had no difficulty in providing a full explanation on the basis of wave theory.) A year later, Biot studied rotatory polarization in various crystals and orga nic solutions, discovered that while some crystals rotate the light to the right others rotate it to the left, and determined that the rotation is proportional to the thickness of substance traversed and to the wavelength of the light.

The Frenchmen Francois Arago and Jean-Baptiste Biot didn't see eye-to-eye. Arago discovered "interference colors" by placing a sheet of mica between a glass reflector and a calcite prism. Imagine the impression that the striking colors must have made on him! He also noticed that the colors remained if the glass reflector was missing but the background was the sky: the blue sky must be polarized! He also saw evidence of circular polarization by replacing the mica by a quartz crystal. He presented a paper to the Paris Academy in 1811 on his preliminary results. But the next year Biot (a previous collaborator) jumped-the-gun on him by presenting two papers much more comprehensive, taking the field away from him (he is considered the discoverer of circular polarization). Biot also studied the sky polarization and found that the rainbow was polarized (Brewster saw a beautiful confirmation of Descartes law and his polarizing angle on this fact). Arago took revenge on Biot by helping his protege, Fresnel, develop the wave theory of light, as Biot was a lifetime corpuscular. Arago didn't like Napoleon either and refused in 1852 to take the oath of allegiance.

The rich colours produced by polarized light passing through certain crystals were discovered by Arago in 1811. Partisans of the two rival optical theories hastened to find explanations of this phenomenon of depolarization. On the undulatory theory explanations were given first by Young, then more fully by Arago and Fresnel. On the corpuscular theory, the facts were accounted for by Biot in a complicated research of great mathematical elegance. This was received favourably by Laplace and other mathematicians, who found the speculations of Biot more congenial to their habits of thought than those of Fresnel. Arago entered

[518] N.H. Winchell and A.N. Winchell., *Elements of Optical Mineralogy, An Introduction to Microscopic Petrography*. New York, D. Van Nostrand Company. 1908. 502 p., 350 figs. 4 plates.

[519] Further historical information may be found in: Jed Z. Buchwald., *The rise of the wave theory of light: Optical theory and experiment in the early nineteenth century*. Chicago, University of Chicago Press, 1989. xiv, 498 p., illus. [History of optics in the 18th and 19th century.; ISBN 0226078841.] • W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

the lists against Biot, and the discussion was carried on with such bitterness that the two physicists, once intimately associated, became wholly estranged. Biot gave the important laws of rotary polarization and their application to the analysis of various substances.

In 1811 Arago discovered that if a thick plate of quartz, with parallel faces cut at right angles to the optic axis, be examined in plane polarized light between crossed nicols, it does not appear dark, as one would expect of a uniaxial crystal, but shows an interference tint. If the section be rotated on the stage of the microscope, this color does not change, and, if monochromatic light be used, it is only by rotating one or the other nicol through a certain angle that darkness can be produced. It is perfectly clear, therefore, that the emerging light is plane polarized but not in the direction in which it entered the crystal. In other words, the plane of polarization has been rotated.[520]

The only other natural mineral known to possess the property of rotary polarization is cinnabar. The effect is rather weak in each case. In the former it is about 1/200 as great as the double refraction in a direction at right angles to the axis, in the latter about thirteen times as great as in quartz. Rotary polaaization is found, however, in many organic substances which crystallize in enantiomorphous forms.

All substances which possess the power of rotating the plane of polarization are called active, the others inactive.

While rotary polarization is of interest, it is of no great use in petrography except that advantage is taken of it in the construction of certain sensitive plates, such as that of Biot, Klein, etc.

The amount of rotation depends upon the color of the light used and the thickness of the section, as was shown by Biot.[521] In the table on the following page the values in millimeters for the rotation, given in the fourth column, were determined experimentally by Soret and Sarasin.[522] They may be calculated by Lommel's formula,[523]

Suspecting that rotatory polarization is an effect of a lack of symmetry, J. Herschel established that quartz crystals often present trapezohedral faces placed in such a way that those belonging to certain crystals are mirror images of the corresponding faces of other crystals. He explained the connection between this arrangement and the respective rotation of light to the right and the left. The rotatory polarization of quartz and sodium chlorate was studied by C. Marbach; des Cloizeaux discovered the rotatory polarization of cinnabar and strychnine sulphate.

The rotatory polarization of certain organic salt solutions would have remained beyond the scope of crystallography, had not Pasteur's work with tartaric acid and the tartrates established a connection between this property of solutions and the crystalline form of the solutes (1848-1852). Pasteur gave the general relation between crystal morphology and rotatory polarization.

Basing himself on the discoveries of Biot, Arago and Herschel, Pasteur prepared the sodium ammonium salts of tartaric and racemic acids (which latter is optically inactive in solution) and obtained two kinds of crystal that were mirror images of each other (enantiomorphous). Having carefully separated the two, he discovered that solutions of one were dextrorotatory-that is rotated the plane of polarization to the right-while solutions

[520] F.J. Arago., "Memoire sur une modification remarquable qu'eprovent les rayons lumineux dans leur passage a traiers certains corps diaphanes et sur quelques autres nouieaux phenomenes d'opiique," *Mém. Acad. France, Année*, 1811, Pt. I, **12** (1812), p. 93-134.; German translation, "Ueber eine eigenthiimliche Modification, welche die Lichtstrahlen beim Durchgehen durch gewisse durchsichtige Korper erleiden, und über einige andere neue optische Erscheinungen," *Gilbert's Ann.*, **40** (1812), p. 145-161. [Translation of the preceding by Gilbert.]; *ibid.*, "Memoire sur la polarisation coloree," **Oeuvres Ccompletes**, Paris, X (n.d.), p. 36-74, especially p. 54-55.

[521] J.B. Biot, "Mémoire sur un nouveaux genre d'oscillation que les molecules de la lumiere eprouvent en traiersant certains cristaux. Lu a PInstitute, 31 mai, 1813, et 3 nov., 1813," *Mem. Acad. France, Année*, 1812, Paris, **13** (1814), Pt. I, p. 1-371, especially 218-314.

[522] J. L. Soret et Ed. Sarasin., "Sur la polarisation rotatoire du quartz," *Comptes Rendus*, XCV (1882), 635-638.; *ibid.*, Arch. soc. phys. et nat. de Geneve, LIV (1875) 253, VIII (1882), 5, 97, 201.

[523] E. Lommel: Theorie der Drehung der Polarisationsebene. Wiedem. Ann., XIV (1881), S 23-533.; *ibid.*, "Das Gesetz der Rotationsdisdispersian," *Wiedem. Ann.*, XX (1883), 578-592, particular 592.

of the other were laevorotatory. When aqueous solutions of the two were mixed in equal quantities, the solution became optically inactive. From these results Pastcur concluded that the molecular arrangement of the atoms of these two compounds was also enantiomorphous.

1811: Arago The discovery of the rotation of the plane of polarization of light travelling through quartz was made by Arago.

1821: Biot enunciated the laws of the phenomenon.

1821: Herschel pointed out the relation between the hand of the rotation and the development of faces on quartz crystals.

1822: Fresnel explained the rotation by postulating oppositely circularly polarized beams travelling with different velocities along the optic axis.

1831: Airy gave an explanation of the formation of the spirals which bear his name.

1846: Faraday discovered in 1846 that the plane of polarization may also be rotated when light passes through an isotropic medium when it is in a magnetic field.

1857: Des Cloizeaux advanced a general theory of rotatory polarization. Des Cloiseaux., "Mémoire sur l'emploi des propriétés optiques biréfringentes, pour la distinction et la classification des minéraux cristallisés," *Annales des Mines* (Paris), 11 (1857), p. 261-342.

1864: Stefan introduced the banded spectrum in the study of rotatory polarization.

1892: Goldhammer gave a theory of magnetic optics in ferromagnetic crystals.

1893: Drude studied optics in ferromagnetic crystals.

In 1911 Fredrich E. Wright presented an investigation undertaken primarily to determine the influence of certain factors which underlie the methods for the measurement of the optic axial angles, especially the method of Professor Becke and the writer's modification of the same.[524]

1915: Voigt gave a theory of magnetic optics in ferromagnetic crystals.

### 5.6.4 Optical Properties and Heat[525]

**REWORK:** Brewster and Mitscherlich showed experimentally that, in certain crystals, the angles between the faces, the angles between the optical axes, and the direction of the planes may vary with the external temperature. Neumann investigated this property in gypsum and borax, and Des Cloizeaux, working with biaxial crystals, discovered in particular that orthoclase changes permanently when the temperature exceeds 700°C. This discovery was of great interest to geologists, who had found that certain volcanic rocks contained what Des Cloizeaux called 'deformed orthoclase'.

Effect of Heat on the Form and Double Refraction of Calcareous Spar. — That active and eminent chemist M. Mitscherlich, observed, upon measuring the angles of calcareous spar at different temperatures, that there was a variation of 8' 30" in passing from 0° to 100° of the centigrade scale. The dihedral obtuse angle diminishes by heat, or the short axis of the rhomboid is more dilated than the other diagonals, so that its form approaches to that of a cube. Mitscherlich conjectured that its double refraction would also diminish by heat, and this was proved by M. Fresnel to be the case. The same effect, but in a lesser degree, was produced in rock crystal ; but M. Fresnel observes that the experiment was not repeated. H enee it appears, that heat uniformly distributed in a crystal diminishes the double refraction. M. Mitscherlich is of opinion, that heat should always separate most the particles of a crystal in the direction in which they are nearest each other.

M. Fresnel likewise found, that heat dilates sulphate of lime less in the direction of its principal axis of double refraction (in the plane of the laminiE *) than in a direction perpendicular to it; a difference analogous to that in Iceland spar, but of a contrary character, as might ) been expected, from the

[524] F.E. Wright, "Transmission of light through transparent inactive crystal plates, with special reference to observations in convergent polarized light," *American Journal of Science*, 4th series, **31** (1911), p. 157-211. [Gives a good number of earlier references at the articles introduction.]

[525] Further historical information may be found in: W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

opposite nature of the double refraction two minerals. See Bulletin des Sciences, Dec. 1823, p. 181.

Other minerals containing rare earths (thorite, gadolinite, euxenite, etc.) become incandescent at a fixed temperature. Des Cloizeaux called them 'pyrognomic' minerals and, in collaboration with Damour, studied their optical properties. In the 20th century it was shown that the special properties of these minerals are linked to the presence in them of radioactive elements.

In 1824 Eilhardt Mitscherlich [1794-1863] published a memoir describing the effects of temperature change on the dimensions of a number of crystals of various substances.[526] First, he demonstrated that crystals that were regular geometric solids, like the cube, the regular octahedron, and the rhombic dodecahedron, expanded uniformly in all directions upon a temperature increase and evidenced no change in the value of their interfacial angles. Second, crystals having rhombohedra or hexagonal prisms for their primitive forms displayed unequal expansion in one direction when they were heated. For example, calcite expanded nonuniformly in the direction of its vertical axis, whereas its expansion was uniform in the other two axial directions. Hence, crystals with one axis of double refraction reacted in exactly the same manner to heat as to light. Third, all crystals shown to possess two axes of double refraction expanded unequally in all three directions when heated. Mitscherlich concluded from his experiments that the expansion of crystals upon heating was related to the axes of crystallization and that these axes corresponded with the optical axes.

Neumann not only established a rapid change in the angle between the optical axes of the gypsum as a result of its heating, but also attained the interference pattern of the uniaxial crystal of the as a result maximum rapprochement of these two axes. To it, in 1833 g. analogous phenomenon in the crystals of glauberite described d. Brewster (in the red light glauberite optically of [dvuosen], A in violet- it is uniaxial).

1832: Duhamel gave the first experiments on thermal conduction in crystals.

1847: Senarmont introduced the method of plotting isothermal surfaces surrounding a point source of heat in a crystal plate. He made observations on many crystals and measured the ratios of the coefficients of thermal conductivity for different directions of heat flow. Between 1847 and 1850 the French crystallographer and mineralogist Senarmont [1808-1850] who was a tireless researcher of minerals, began studying the optical properties of crystals, and is perhaps the first to understand the importance of optical methods. He established in his studies the analogy between the optical properties of crystals and their thermal conductivity.

1851: Stokes made an analysis and raised questions as to how heat flowed in the crystals.

1864: Fizeau used an optical interference method to make measurements on many crystals. The measurements of the change of interfacial angle and the expansion of cut plates and bars were applied to crystals of all symmetries.

1884: Stenger made experiments to determine the heat flow in crystals.

1898: Tutton used a highly developed interferometer for measurements on a num-ber of sulfates of various metals.

### 5.6.5 Pleochroism & Absorption[527]

**REWORK:** The color of a transparent mineral is due to the residual color of the light spectrum left after the substance has absorbed a certain part of it. Many colored anisotropic crystals have the property of absorbing different amounts or kinds of light in different

[526] E. Mitscherlich., "Ueber das Verhältnis der Form der kristalliserten Körper zur Ausdehnung die Wärme," in: A. Mitscherlich., *Gesammelte Schriften von Eilhard Mitscherlich*. Berlin, 1896, p. 195.

[527] Further historical information may be found in: T. Crook., "Some observations on pleochroism and idiophany in mineral plates," *Mineralogical Magazine*, **16** (1911), no. 73, p. 1-29. [See the "Historical résumé" section, p. 22-28.] • J.A. Mandarino., "Absorption and pleochrosim: Two much-neglected optical properties of crystals," *American Mineralogist*, **44** (1959), p. 65-77. • Shafranovskii, *Istoriia kristallografii XIX vek*, 1980, p. 86. • W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

directions. Absorption has reference to the amount or intensity of light absorbed and hence may be tested in monochromatic light while pleochroism refers to the kind of light absorbed and so must necessarily be tested in white light.

Some crystals, viewed by transmitted light, present different colors in different directions. This property is termed pleochroism, (from the Greek "Xeos", full, and "xxxx" color), or dichroism, (from "xxx", two-fold, and "xxxxx") when the colors are different in two directions only. This property is exhibited by crystals which have at least two kinds of axes; the colors are the same in the direction of like axes, and different in the direction of unlike axes. lolite owes its name (dichroite) to this property. Mica is nearly opaque in one direction, while it is transparent and of a different color in another. Monometric crystals are sometimes pleochroic, the color differing in the direction of unlike diagonals.

In uniaxial crystals with monochromatic light the two rays corresponding to any direction of transmission are in general absorbed at a different rate. The faster ray may be either more absorbed or less absorbed than the slower, the absorption of the ordinary ray being independent of the direction of transmission, while that of the extraordinary varies with the inclination to the optic axis, but is constant for the same angle and differs most from that of the ordinary for transmission normal to the optic axis. With white light the color seen in any direction will be due to a combination of the ordinary and extraordinary rays, and this combination will give different tints in different directions. Pleochroism is the property of a mineral to exhibit different colors in different crystallographic directions on account of the selective absorption of transmitted light. The measurement of pleochrosim is made with a device called the dichroscopic (see §14.6.3).

In 1809 the French mineralogist Pierre Louis Antoine Cordier [xxxx-xxxx] during his investigation of a new mineral he named dichroïte revealed the phenomenon of pleochroism.[528] The mineral was remarkable because it exhibited the curious property that its crystals showed two distinctly different colors when viewed along two different axes: a dark blue parallel to the [001] axis, and a pale yellow perpendicular to it. In 1813 Jean-André-Henri Lucas [xxxx-xxxx] , a supporter of Haüy, redescribed the mineral, changing its name from dichroïte to cordierite in honor of its discoverer.[529] Haüy and his supporters retained the essence, however, and coined the word "dichroism" to describe the property of a crystal showing two different colors. As a note of interest, other investigations of the interaction of light with cordierite showed that along the third axis [010] the color was altered to a yellowish-gray.[530] Therefore the term "trichroism" was coined, becoming a companion word to "dichroism."

Starting in 1817 David Brewster [xxxx-xxxx] made a general study of the light absorption and pleochroism in varoius minerals. According to his observations, the prism of bluish-green beryl seemed in polarized light to turn blue, when its axis was oriented perpendicular to the plane of polarization, and greenish when the axis was parallel to this plane. Analogous phenomena were noted by the scientist for other minerals. By 1819 Brewster had completed a systematic study of the absorption of light by crystals, and showed that, in uniaxial crystals, the absorption is smallest in the direction of, and greatest at right angles to, the optical axis.[531] Among the minerals he examined with both normal and polarized light were sapphire, epidote, mica, and cordierite (dichroïte). He was, however, unable to discover the more complex

[528] P.L.A. Cordier., "Description du dichroïte, nouvelle espèces minérale," *Journal des Mines*, **25** (1809), p. 129-???. [The mineral was named after **GREEK xxx**, 'double,' and **GREEK xxxxx**, 'color,' because it transmits two colors.]

[529] J.A.H. Lucas., *Tableau Méthodique des Espèces Minérales*, **2**, 1813, p. 219.

[530] W. Haidinger., "Ueber den Cordierit," *Annalen der Physik (Poggendorff)*, **67** (1846), p. 441-467.

[531] D. Brewster., "On the Laws which regulate the absorption of polarised light by doubly refracting crystals," *Philosophical Transactions of the Royal Society of London*, **1819**, p. 11-28.; *ibid.*, "On the absorption of polarised light by doubly refracting crystals," *Edinburgh Philosophical Journal*, **2** (1820), p. 341-348.; *ibid.*, "On the phenomena of dichrosim," *Edinburgh Philosophical Journal*, **3** (1820), p. 244-???.

laws governing absorption in biaxial crystals.

Later investigations by John Frederick William Herschel [xxxx-xxxx] confirmed the property of pleochroism, and brought about further substantial progress to the knowledge of the optical characteristics, particularly absorbtion of light in biaxial crystals.[532] His paper also gives an elegant explanation for the interference rings first observed by Brewster in 1818 and which are the keystone to the foundation of optical mineralogy studies of the 19th and 20th centuries.

The absorption of light in crystals continued to be investigated in the 19th century, but it did not progress beyond a rule-of-thumb system until much later. Among the earlier investigators was Jacques Babinet [xxxx-xxxx] , who in 1838 discovered that the greatest absorption in a crystal generally coincided with the direction of greatest refractive index.[533] He found many exceptions to this rule, however.

In 1845, Wilhelm von Haiginger [xxxx-xxxx] made a general account of pleochroism in crystals.[534] Haidinger also published again on pleochrosim.[535]

In 1854, at the end of his career Henri Hureau de Sénarmont [xxxx-xxxx] investigated the property of pleochroism. Suspecting that the unequal absorption of light in different directions occurred because of the coloring agents inside the crystal, he created some artificial crystals to which he introduced coloring agents. As he predicted these crystals became extremely pleochroic.[536]

1862: Gustav Rose [xxxx-xxxx] [537]

1862: E. Reusch [xxxx-xxxx] [538]

1862: Franz von Kobell [xxxx-xxxx] [539]

1869: Haushofer [xxxx-xxxx] [540]

1869: Kosmann [xxxx-xxxx] [541]

1877: P. Glan [xxxx-xxxx] performed photometric observations on absorption in 1877. [542]

1880: H. Laspeyres [xxxx-xxxx] (1880) pointed out the existence of absorption axes (directions of least, intermediate, and greatest absorption).[543] He investigated certain biaxial crystals and found that the absorption axes, although subject to the symmetry of the crystal, did not necessarily coincide with the principal directions of the indicatrix.

In 1888, Henri Becquerel [xxxx-xxxx] made qualitative and quantitative observations.[544]

1890: P. Drude [xxxx-xxxx] gave in 1890 a theory of the absorption of light in strongly absorbing crystals. [545]

[532] J.F.W. Herschel., "On the action of crystallized bodies on homogeneous light, and on the causes of the deviation from Newtons scale in the tints which many of them develope on exposure to a polarised ray," *Philosophical Transactions of the Royal Society of London*, **1820**, I, p. 45-100.

[533] J. Babinet., "Sur l'absorption dans les milieux colores birefringents," *Comptes Rendus, Acad. Sci. Paris*, **7** (1838), p. 832-833.

[534] W. von Haidinger., "Ueber den Pleochroismus der Krystalle," *Annalen der Physik (Poggendorff)*, **65** (1845), p. 1-30.; *ibid.*, "Ueber das Schillern der Krystallflächen," *Annalen der Physik (Poggendorff)*, **70** (1847), p. 574-???, **71** (1848), p. 321-343, and **76** (1849), p. 99-??.

[535] W. Haidinger., "Pleochroismus an mehreren einaxigen Krystallen in neuerer Zeit beobachtet," *Sitzungsberichte der Mathematisch-Naturwissenschaftlichen Classe (Wien)*, **13** (1854), p. 3-17; *ibid.*, "Pleochroismus einiger zweiaxiger Krystalle," *Sitzungsberichte der Mathematisch-Naturwissenschaftlichen Classe (Wien)*, **13** (1854), p. 306-331.

[536] H. de Sénarmont., "Remarques sur les propriétés optiques de quelques sels," *Annales de Chimie et de Physique*, 3 Serie, **41** (1854), p. 319-335.; *ibid.*, "Versuche über die künstliche Erzeugung von Polychroïsmus in krystallisirten Substanzen," *Annalen der Physik (Poggendorff)*, **167** (1854), no. 3, p. 491-494.

[537] G. Rose., "Ueber den Asterismus der Krystallen," *Ber. Ak. Berlin*, **1862**, p. 614-???, and **1869**, p. 344-???.

[538] E. Reusch., "Ueber das Schillern gewisser Krystalle," *Annalen der Physik (Poggendorff)*, **116** (1862), p. 392-???, **118** (1863), p. 256-???, and **120** (1863), p. 95-??.

[539] F.v. Kobell., "Ueber Asterismus und die Brewsterschen Lichtfiguren," *München, Sitzungsber*, 1862/I, p. 199-209.; *ibid.*, "Ueber Asterismus. Stauroskopische Bemerkungen," *München, Sitzungsber*, 1863/I, p. 65-66.

[540] ??. Haushofer., "Ueber Asterismus des Calcites," *Ber. Ak. München*, 1869, p. ??-??.

[541] ??. Kosmann., "Ueber das Schillern und den Dichrosimus des Hypersthens," *Neues Jahrbuch für Mineralogie*, **1869**, p. 368-??? and p. 532-???, and, **1871**, p. 501-???.

[542] P. Glan., "Ueber ein neues Photometer," *Annalen der Physikalsiche Chemie*, **1** (1877), p. 351-360.

[543] H. Laspeyres., "Mineralogische Bemerkungen," *Zeitschrift für Krystallographie*, **4** (1880), p. 433-467.

[544] H. Becquerel., "Recherches sur les variations des spectres d'absorption dans les cristaux," *Ann. Chim. (Paris)*, **14** (1888), p. 170-257.; *ibid.*, "Sur les variations des spectres d'absorption des composés du didyme," *Ann. Chim. (Paris)*, **14** (1888), p. 257-279.

[545] P. Drude., "Das Verhalten der Absorptions-coëfficien-

Otto Lehman [xxxx-xxxx] like Sénarmont studied pleochroism in artificial crystals.

Between 1880 and 1900, W. Voigt [xxxx-xxxx] (1885),[546] and P. Drude (1900)[547] presented the fundamental theories of absorption in crystals. During this same period, notable experimental work confirming these theories was carried out by W. Voigt (1885),[548] Becquerel (1887),[549] Ramsay (1888),[550] and Ehlers (1898).[551]

1898: Woldemar Voigt [xxxx-xxxx] included a great deal of information on pleochroism effect in his important textbook, *Die Fundamentalen Physikalischen Eigenschaften der Krystalle* (1898).

1902: W. Voigt [xxxx-xxxx] [552]

1906: A excellent summary of crystal optics was compiled by F. Pockels [xxxx-xxxx] and published as his *Lehrbuch der Kristalloptik* in 1906. He includes information on pleochrosim.

1911: T. Crook [xxxx-xxxx] ...[553]

Literature

1903 Georges Meslin., "Mesure du dichxoïsme du cristaux," *Paris, Acad. C. R.*, **137** (1903), 3 p.

### 5.6.6 Optical Anomalies[554]

**REWORK:** The optical symmetry of many crystals is lower than would be expected from their external form and X-ray diffraction data. Recently such optical anomalies have been attributed to nonequilibrium structures resulting from kinetically controlled crystal growth. Impurities are incorporated to different extents at various surface sites that would otherwise have become symmetry-related within the bulk crystal. After their discovery by Brewster in 1815, optically anomalous crystals were the subject of lively debate throughout the 19th century among some of the most distinguished contributors to the development of crystallography including Biot, Berzelius, Herschel, Mitscherlich, Frankenheim, Pasteur, Mallard, Klein, Groth, Wyrouboff, Barlow, Brauns, Rinne, Pockels, and Friedel. From a sea of wild speculation two conflicting postulates emerged: that the symmetric form resulted from accidental twinning of segments with lower symmetry, or that the optical peculiarities resulted from stress due to impurities or external perturbations. Neither postulate expresses the present view. Interest in this research waned at the turn of the century, and after 1917 no one pursued Tammann's alternative correct insight.

1851: From his study of isomorphic crystals, de Senarmont concluded in 1851 that salts which were chemically and geometrically isomorphic may nevertheless have quite distinct optical properties. He devised experiments in order to investigate the reason why certain natural groups of minerals, such as mica and topaz, have inconstant optical properties.

1880s: Mallard showed that anomalous crystals are built up of distinct parts, whose symmetry is less than that of the whole but which are so arranged as to form a more symmetrical structure. Pasteur had previously shown that whenever a mineral species can produce crystals belonging to two distinct systems, the more symmetrical form is a limiting case of the less symmetrical form. Applying this view to compound systems,

ten von Krystallen," *Annalen der Physikalsiche Chemie*, **40** (1890), p. 665-680.

[546] W. Voigt., "Erklärung der Farbenerscheinungen pleochroitischer Krystalle," *Neues Jahrbuch für Mineralogie*, **1885**/I, p. 119-141.

[547] P. Drude., *Lehrbuch der Optik*. Leipzig, S. Hirzel, 1900.

[548] W. Voigt., "Erklärung der Farbenerscheinungen pleochroitischer Krystalle," *Neues Jahrbuch für Mineralogie*, **1885**/l, p. 119-141.

[549] H. Becquerel., "Sur l'absorption de la lumiere au travers des cristaux," *Bulletin Société de Minéralogie France*, **10** (1887), p. 120-124.

[550] W. Ramsay., "Ueber die Absorption des Lichtes im Epidot vom Sulzbachthal," *Zeitschrift für Krystallographie*, **13** (1888), p. 97-134.

[551] J. Ehlers., "Die Absorption des Lichtes in einigen preochroitischen Krystailen," *Neues Jahrbuch für Mineralogie*, **1898**/ll, p. 259-317.

[552] W. Voigt., "Beiträge zur Aufklärung der Eigenschaften pleochroitischer Krystalle ," *Annalen der Physik*, **314** (1902), no. 10, p. 367-416.

[553] T. Crook., "Some observations on pleochroism and idiophany in mineral plates," *Mineralogical Magazine*, **16** (1911), no. 73, p. 1-29.

[554] Further historical information may be found in: Bart Kahr and J. Michael McBride., "Optically Anomalous Crystals," *Angewandte Chemie International Edition in English*, **31** (2003), no. 1, p. 1-26. • W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

Mallard was able to account for the existence of twins and to offer a tentative theory of polymorphism.

1891: Brauns, in his *Die optischen Anomalien der Krystalle* (Leipzig, 1891) published a compendium of all known facts about optical properties of minerals. But the new techniques provided by the powerful study lead to many discrepancies between optical theory and observed facts. Some crystals with cubic symmetry are, for example, doubly refracting when they should theoretically be isotropic. Others are biaxial when their symmetry suggests they must be uniaxial.

1910: The study of opaque crystals was greatly developed by J. Konigsberger

1917: Gaubert (1917) studied the rotatory power of anisotropic liquids.

1920: Seve (1920) and Gaudefroy (1924) continued the study of double refraction.

### 5.6.7 Reflection[555]

**REWORK:** The study of the optical properties of opaque substances has been closely linked with the development of suitable microscopes.

1813: Berzelius introduced the use of polished and etched surfaces for this type of study.

1848: Cauchy built a theory of the light reflected from metals was put forward.

1888: Drude worked on antimony sulfide.

1913-1937: Berek showed what quantities need to be measured in anisotropic materials.

1972: A survey of the subject is given by Orcel in *Microscopic Study of Opaque Minerals* (1972) by Galopin & Henry.

### 5.6.8 Infrared Optics

**REWORK:** 1897: Rubens & Niçois studied the 'Reststrahlen' (residual rays) obtained when infrared rays of appropriate wavelength are reflected from surfaces of the crystals.

1927: A summary of the research carried out between 1918 and 1927 is contained in Rawlins & Taylor, *Infra-Red Analysis of Molecular Structure* (1929).

[555] Further historical information may be found in: W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

## 5.7 Electrical Properties[556]

The relative conducting power of electricity through different minerals was a subject of minor interest in the early development of mineralogical science; however, interest in the property advanced with technological growth. In the form of either frictional electricity or the pyroelectrical effect electricity was one of the earliest qualities used to identify a particular mineral species. For example, amber was known in ancient times to attract small feathers after obtaining a static charge after being vigorously rubbed. Such curious effects gave way to many useful applications as electrical technology and theory advanced. Conductivity is today a property that is highly valuable in ore deposit exploration and it is a property that enables many modern electronic devices to operate. Every computer has at its heart a vibrating crystal regulated by the piezoelectric effect that moderates the flow of electrons through the circuitry.

### 5.7.1 Pyroelectricity[557]

**REWORK:** Pyroelectricity was probably first observed centuries ago. The Greek philosopher Theophrastus, who lived in the fourth century B.C.E., probably wrote the earliest description of the pyroelectric effect, as exhibited by the mineral tourmaline. He described a stone called lyngourion that had the property of attracting straw and bits of wood. Theophrastus had

[556] Further historical information may be found in: Edmund Hoppe., *Geschichte der Elektrizität*. Leipzig, Johann Ambrosius Barth, 1884. xx, 622 p. [History of electricity.; Reprinted, Wiesbaden, Sändig, 1969.] • W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

[557] Further historical information may be found in: Wilhelm Gottlieb Hankel., "Uebersicht über die Entwickelung der Lehre von der Thermoelektricität der Krystalle," *Abhandlung der sächsische Gesellschaft der Wissenschaften*, **10** (1874), p. 345-??. [Includes a history of pyroelectricity.] • S.B. Lang., *Sourcebook of pyroelectricity*. London, New York & Paris, Gordon and Breach Science Publishers, 1974. xv, [1], 562 p., biblio., illus., index. [Contains a good history and excellent bibliography of pyroelectricity.] • Peter Theophil Riess, *Die Lehre von der Reibungselektricität*. Berlin, 1853. [Volume two, page 453 starts a history of pyroelectricity.] • W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

thus observed the effects of electrostatic charges due to temperature changes of a pyroelectric material. Although our present scientific interests concern the powers of attraction of lyngourion, Theophrastus and subsequent authors in the following two millennia were far more interested in the origin of the stone and its possible therapeutic properties. Theophrastus proposed that lyngourion was formed from the urine of an animal called a lynx. This was not the cat known today, but a doglike animal.

About 300 years later, Pliny the Elder, a Roman historian of the first century AD, repeated the story, giving the stone a Latin name, lyncurium. More than 35 further works mention lyncurium, largely repeating the accounts of Theophrastus and Pliny with some embellishments. These works and authors include the Greek geographer and historian Strabo (c. 7BC); a collection of Greek manuscripts called the Alexandrine lapidaries' (AD227-400); Epiphanius, Bishop of Salamis on Cyprus (c. AD400); the Spanish historian Isidore of Seville (c. AD600); and Marbodus, Bishop of Rennes in France (c. AD ll00). An especially graphic description of the origin of lyncurium and its medicinal properties is given by Dioscorides, a first century AD Greek herbalist: 'But that [urine] of the Lynx, which is called Lyncurium, is thought as soone as it is pist out, to grow into a stone, wherefore it hath but a foolish report. For it is this that is called by somme, Succinum pterygopho-ron [because it drawes feathers to it], which being dranck with water is good for the stomach & for a belly that is troubled with a flux.'

One of the most beautiful of the ancient books on natural history is the 'Hortus sanitatis major', the 'Garden of health', which describes the medicinal and therapeutic values of many plants, animals and minerals. Perhaps written by Johann Wonnecke of Caub in the fifteenth century and was published in Latin, German, French, Dutch and Italian editions. Lyncurium is described in several chapters.

### Eighteenth Century

Two thousand years after Theophrastus, the unusual physical properties of tourmaline were reintroduced into Europe through the publication in 1707 of a book entitled *Curiöse Speculationes bey Schlaflosen Nächten* ('Curious speculations during sleepless nights'). The author of the book, Johann Georg Schmidt, using the pen name Immer Gern Speculirt ('Always Gladly Speculating'), wrote a series of 48 dialogues, one of which contained a section describing hard and glassy bodies which were not magnetic. An excellent description of the pyroelectric effect in tourmaline is given in this passage:

> The ingenious Dr. Daumius, chief physician to the Polish and Saxon troops on the Rhine, told me, that, in the year 1703, the Dutch first brought from Ceylon in the East Indies a precious stone called tourmaline, turmale, or trip, which had the property of not only attracting the ashes from the warm or burning coals, as the magnet does iron, but also repelling them again. This sight was very amusing, for as soon as a small quantity of ashes leaped upon it, they appeared to be endeavouring to writhe themselves by force into the stone. Soon a few of the ashes jumped from it again, as if to leap to the tourmaline again. For this reason, it was called the ash-drawer by the Dutch. The colour of it was an orange-red heightened by a fire colour. When the turf coals were cold, the tourmaline did not produce these effects, and it required no care like the magnet ... I have considered whether it would not attract and repel the ashes of other burning coals as well as those of turf; and I have no doubt, that, if heated, it would attract other things besides ashes.

The first description of pyroelectricity in a scientific journal was by a physician and chemist, Louis Lemery, who exhibited a tourmaline crystal before the Academy of Sciences of Paris in 1717. The naturalist Carl von Linné (Linnaeus) was the first person to relate the pyroelectric property of tourmaline to electricity. He called the mineral lapis electricus. The first serious scientific study of the electrical properties of tourmaline was presented to the Royal Academy of Sciences in Berlin by Dr Franz Ulrich Theodor Aepinus in 1756. His major observations were that tourmaline became electrified by being warmed (rather than by friction which was the common method in use at the time), and that the crystal acquired opposite electric charges on two opposing faces. Aepinus' observations strongly supported Benjamin Franklin's theory

of positive and negative electricity, against the strong and weak electricity theory of Abbé Nollet.

The usefulness of this new way of generating electric charges and its relevance to the rapidly developing understanding of electricity and magnetism induced many others to experiment on tourmaline, including Johann Karl Wilcke, Benjamin Wilson, Joseph Priestley, John Canton and Torben Bergman. Canton was apparently the first person to observe that cooling of tourmaline caused its electrical polarity to be the reverse of that found on heating. He also devised a very novel experiment for demonstrating that the quantities of positive and negative charge were equal. He connected a metal cup filled with boiling water to a pith ball electroscope. A tourmaline crystal was dropped into the water and the electroscope showed no sign of electric charge, either then or during subsequent cooling of the water. This demonstrated that the absolute quantitites of positive and negative charge produced on the crystal were equal and were neutralised in the water.

During the nineteenth century, research in pyroelectricity began to become more quantitative. As electrical measuring techniques of greater sophistication were developed, these were soon applied to pyroelectric studies.

David Brewster, famous for his work in optics, was the first author to use the term 'pyroelectricity'. It appeared in his 1824 paper entitled 'Observations on the pyro-electricity of minerals'. One of the materials studied by Brewster was the 'tartrate of soda and potash' - Rochelle salt - which was the material in which Valasek discovered ferro-electricity almost exactly a century later. Quantitative electrometers for charge measurement were developed by A. C. Becquerel, James D. Forbes and Wilhelm Gottlieb Hankel. Hankel was one of the most prolific writers of all time on pyroelectricity, and published more than 30 very lengthy papers between 1839 and 1899.

Jean-Mothée Gaugain made the first precise measurements of pyroelectric charges in 1859. He reached some important conclusions: first, that the total quantity of electricity produced by a crystal of tourmaline depends uniquely upon the limits within which its temperature is varied; second, that within the same temperature limits, the quantity of electricity produced during heating is the same as that produced during cooling, but with the signs of the charges reversed; and third, that the quantity of charge produced is proportional to the cross-sectional area of the crystal and is independent of its length. The first major theoretical treatment of pyroelectricity was published by William Thomson, Lord Kelvin, in 1878. He was also the first person to predict the electrocaloric effect, the converse effect of pyroelectricity. A much used technique for determining the charge distribution on a crystal was developed by Kundt in 1883. A mixture of red lead oxide and sulphur was dusted onto the crystal. The lead oxide adhered to the negative parts of the crystal and the sulphur to the positive parts. Jacques and Pierre Curie speculated that the electrical effects due to non-uniform heating of quartz crystals might be caused by pressure, which led to their discovery of piezoelectricity in 1880 (see §5.7.3). Woldemar Voigt, professor of physics at the University of Göttingen from 1883 to 1919, established an outstanding school of crystallography, thermodynamics and crystal physics. Many of the publications emanating from his school are described in his 'Lehrbuch der Kristalphysik'.

During the latter part of the nineteenth century and the early decades of the twentieth, seven Nobel laureates published papers on pyroelectricity. They are, of course, much better known for their research in other fields.

Few important papers on pyroelectricity were published in the first two decades of the twentieth century. Joseph Valasek studied the properties of Rochelle salt and, in 1920, discovered ferroelectricity. Interest in pyroelectricity for a while then virtually vanished.

### 5.7.2 Conductivity[558]

[558] Further historical information may be found in: Edmund Hoppe., *Geschichte der Elektrizität.* Leipzig, Johann Ambrosius Barth, 1884. xx, 622 p. [History of electricity.; Reprinted, Wiesbaden, Sändig, 1969.] • W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of*

**REWORK:** Towards the end of the 18th century the electrical conductivity was one of the properties studied for mineral determination. However, little was understood of the nature of electricity and its value as a diagnostic in mineralogy was limited.

In 1787, René Just Haüy presented his first detailed studies of electrical phenomena in his *Exposition Raisonnée de la Théorie de l'Électricitè et du Magnétisme*,[559] in which, like Franklin and Aepinus, Haüy assumed there was a hypothetical electrical fluid and a magentic one. Electrical phenomena would intrigue Haüy through out the remainder of his life, and he would publish several articles about his investigations on the electrical properties of minerals and crystals.[560] Generally, his method was to determine if a mineral showed positive and negative electrical charge after being rubbed with a cloth (static electricity). In 1817, Haüy used his mineralogical electrometer or *????????????* to study electricity that developed when he applied pressure to a crystal. This phenomena is now known as the piezoelecrical effect and is described in a subsequent section.

Minerals were also studied for their ability to generate a current when used in electrochemical combinations. In the year 1806 Guyton tested a variety of minerals for their electrical production. Using a diamond cathode submerged in a water solution, he studied the amount of electricity created when other cathodes of graphite, stibnite, pyrite, and chalcopyrite were submerged in the water. He observed that while a current was created, some of the minerals also infused the water with sulfur from the electrolytic breakdown of the sulfide minerals. Guyton speculates that a larger version of this process could be used commercially in the refinement of sulfur containing ore minerals. He suggests that such a unit should be built and tested in France, but this apparently never happened.

The following year, Davy successfully separated elemental metallic potassium from potash by using an electrical current as the reducing agent. This important discovery led Simon in the year 1808 to reduce many minerals through the application of an electrical current. Using this procedure he was the first to successfully isolate a silicate component ($SiO_x$) from a more complex compound. Davy was also able to reduce silicon to its oxide form, but believed that it was still a compound. But try as he might, Davy was not able to reduce it further.

In the year 1812 a pupil of Haüy, Pellitier presented before the royal university in Paris his thesis, *Essai sur la valeur des caractères physiques employés en minéralogie*[561] that evaluated and described each of the physical properties employed in deterministic mineralogy. In his tenth section, he treats electrical properties specifically. Many of his speculations were later confirmed by other researchers.

Other French mineralogists of the time used electrical conductivity as a property in mineral determination, noting if a particular species was electrically conductive. But the property was never used as an important property in determining a mineral's species.

After Pellitier's study a rather long stretch occurs when no new research in the electrical properties of minerals are researched. In 1834, Heinrich and Hausmann in a rather obscure study recorded the results of their research into the electrical resistance of minerals. Using a Leydner Jar they observed whether a spark was initiated when the mineral in question was touched to the charge bar.

In 1838, Rosienscheold examined numerous artificial and natural sulfur compounds for their conductivity by means of an electroscope. He followed the procedure of Heinrich and Hausmann in his approach and also used the Leyden Jar as a discharge device.

The year 1838 also saw the publication of Faraday's *Experimental Researches on*

*crystallography*. New York, Elsevier, 1990.

[559] R.J. Haüy., *Exposition Raisonnee de la Theorie de L'Electricite et du Magnetisme, D'Apres les principes de M. Aepinus, des Academies de Petersbourg, de Turin, &c.* A Paris, Chez la Veuve Desaint, 1787. xxvii, [5], 238 p., 4 plates.

[560] Add list of other articles here.

[561] Pierre Joseph Pellitier., *Essai sur la valeur des caractères physiques employés en minéralogie.* Thesés Université de Paris. Paris, D. Colas, 1812. 26, [2] p.

*Electricity*, which collected together his series of articles that had previously appeared in the *Philosophical Transactions*. Faraday's research presented a strong theoretical foundation for further studies into electrical phenomena. This interest slowly bleed off into mineral studies.

Karsten in 1847 showed that a large variety of sulfide and telluride minerals found in the mines of Nagyag, Romania to be good electrical conductors. Likewise, he showed that quicksilver (native mercury) to be a conductor, but found its common sulfide ore species cinnabar to not be a conductor.

Heidmann constructed the "Diagometer" to test the electrical conductivity of various substances that had been powdered. This included minerals. It was developed by Heidmann as a new variation of Coulomb's Turning Balance. This was later modified by Rosseau.

Following Faraday's research, Beoquerel wrote a textbook on electricity that became popular and famous.[562] It went far in clarifying the electrical theory of the time. Beoquerel also advances the hypothesis that some mineral formation occurs in the earth by the action of electrocapillaires drawing in a mineralized solution and through a process of natural electrolysis reducing out the ore mineral. He believed that this formation occurred over the course of many years.

The electrical conductivity of minerals still locked within the earth was the focus of Fox's 1835 study. Working in the mines of Cornwall, he successfully measured an electrical current at one location after inducing the current at another location located much further away. This was an exciting result. Fox hypothesised from his experimental success that some metallic ores are formed by the deposition from aqueous solutions through natural electrochemical reactions, and that new ore deposits are being continually formed in the earth along channels through which subterranean water flowed.

Henwood repeated and confirmed Fox's experiments. Fox's genetic theory of ore formation was violently attacked and rejected by other researchers, however. Reich was hired by the local mining concern of Freiberg to evaluate the theory and determine if there was any practical application to be used. Reich concluded that there were those individual cases where the detection of an electrical current could be successfully used to locate new ore deposits. It was not until the later half of the 20th century however, that Fox's use of mineral conductivity would be widely used as a tool in geophysics and ore deposit location.

In 1843, Gustav Rose and P. Riess introduced the concept of electrical axes or 'polar axes' in crystals, which possess asymmetric ends on the crystal terminations. Delafosse explained in terms of strings of hemihedral molecules. In ——— the well known physicist A. Kundt [1839-1894] invented a visual representation of the electrical current. By dusting the sample with yellow powder of sulfur and the red dust of minium near the positive and negative ends of the electrical axes, the flow of current would cause the particles to be carried along through electrostatic processes. The method was successfully employed by the Russian Kolepko [1856-1946] in his study of the polar electricity of quartz with respect to its crystallographic symmetry (1884).[563]

Sénarmont attempted in 1849 to define the electrical conductivity of a series of minerals, just as he had thermal conductivity two years previously. He established the directional dependence of surface conductivity in crystals in "Mémoire sur la conductibilité superficielle des corps cristallisées pour l'électricité de tension" (1850).[564] He discovered this dependence by wrapping a crystal in tinfoil (which had been grounded) and by placing a metal point on the crystal surface at a point where a circular piece of the tinfoil had been cut out; the point was then connected to the positive conductor of an electrostatic machine, and the whole apparatus was placed under the glass bell of an air pump. At

[562] ????

[563] Shafranovskii, *Istoriia kristallografii XIX vek*, 1980, p. 209.

[564] *Annales de Chimie et de Physique*, 3rd ser., **28** (1850), 261.

reduced pressure he was able to observe, in the dark, circular or elliptical figures of light, depending on the nature of the crystal. He stated that: "The continuous and silent flux of the electricity of the rarefied air does not, it is true, leave permanent traces; but it does manifest itself in the darkness by a faint light that persists throughout the whole experiment and that makes all its details visible..." In this way, he examined apatite, beryl, tourmaline, quartz, rutile, cassiterite, vesuvianite, sulfur, stibnite, aragonite, calcite, barite, celestite, topaz, staurolite, gypsum, selenite, glauberite, epidote, mica, and feldspar. Sénarmont compared the electrical conductivity he measured to its optical properties and discovered that the greatest electrical conductivity occured in a direction perpendicular to that of the smallest light transmission.

In 1849, Wiedemann drew figures comparing the optical and electrical properties of minerals. He included in the minerals he examined fluorite, alum, apatite, tourmaline, quartz, aragonite, barite, celestite, gypsum, borax, epidote, and feldspar. He noted that the conductivity would sometimes vary from Sénarmont's results and it was not always in tandem to the optical axis. GARLIC and Root confirmed Wiedemann's observations showing that this relationship also arises if the crystal face to be examined is covered in COLLODION.

Riess reported that the best conductivity occurs along the direction of the crystal's cleavage or on the freshest surfaces from a recent fracture. This can be altered due to the humitity of the atmosphere, however. The later investigations into the Dielectric effect by the brothers Curie showed conclusively that the best conduction in a crystal is in the direction of the optical axes.

The mineralogist Kobell in 1850 persued a different method to measure electrical conductivity in his minerals.[565] He held his specimens between zinc cathodes that were submerged in a solution of copper sulfate. He then measured the current coming off the tested mineral in relation to the known electrical current generated by the zinc and copper solution alone. It was a simple method to measure a minerals conductivity. Unfortunately it often gave Kobell inaccurate values for the minerals he studied in this way. They included stibnite, arsenopyrite, sphalerite, cassiterite, pyrolusite, tetradymite, among others.

Another researcher that attempted to provide an exact measurement of a mineral's conductivity was Wartmann. He investigated 319 mineral species and showed that 252 to be electrical insulators. His technique was to apply a very strong electrical current to the specimen and measure the resulting transmission of the current across the crystal face with a very sensitive Rhumkorff Rheometer.

In 1855, the first observations on the variation of the electrical conductivity with direction in a crystal were made on bismuth by Matteucci.[566]

Bäckström did research on the conductivity with direction in a crystal of hematite, a crystal of rhombohedral symmetry.[567]

As for the flow of heat, the same discussions occurred concerning the equality of resistance to electric currents flowing in opposite directions on a given crystal and the linear or spiral lines of flow from a point source. The application of a magnetic field can curve the lines of current flow and this gives rise to the Hall effect. The Hall effect has in recent times been successfully applied to the study of semiconductors because it helps to distinguish between the positive or negative character of the carriers of electric charge.

Beijerinck[568] in 1897 contributed an exhaustive paper upon the electric conductivity

[565] Franz von Kobell., "??????????????", *Münch. gel. Anzeigen*, **1850**, 89-90.

[566] C. Matteucci., "Sur certaines propriétés physiques du bismuth cristallisé," *C.R..Acad. Sci.*, **40** (1855), 541-545. *ibid.*., "Supplément au mémoire com-muniqué à l'Académie sur certaines propriétés physiques du bismuth cristallisé," *C.R. Acad. Sci.*, **40** (1855), 913-914.

[567] H. Bäckström., "Beiträge zur Kenntnis der Thermoelektricität der Krystalle," *Ofvers. K. Vetensk. Akad. Foerh.*, **8** (1888), 553-559.

[568] F. Beijerinck, "Ueber das Leitungsvermögen der Mineralien für Elektricität," *Jahrbuch der Mineralogie*, Beilage Band, **11** (1898), 403-74. [Exhaustive paper on the electric conductivity of minerals, together with an interesting historical introduction to the subject.]

of minerals, claiming that electric conductivity is a "substantial property which in the case of opaque and heavy or massive minerals is of the greatest importance"; that "no physical property in itself, between wide limits, can he determined with greater accuracy than the electrical resistance of a substance, and that the changes of this resistance, through other physical influences, as for instance the temperature, is in the highest degree characteristic." His tables embraced 375 substances. He concluded that the electrical conductivity of minerals varied between extreme limits, that it was dependent upon the' chemical constitution of the minerals, and upon their position in the System. Chemically isomerous as well as physically allotropic bodies are greatly contrasted in their electric conductivity whereas isomorphous salts are much less contrasted, and differ amongst themselves no more than different metals. Slight differences are evident in different crystallographic axes in anisotropic minerals as in rhombic Marcasite, in the direction of the three axes. Monoclinic and triclinic crystals are non-conductors, above low resistances, but there is no apparent direct relation between the class of symmetry and the galvanic conductivity.

### 5.7.3 Piezoelectricity[569]

Piezoelectricity is the name given to the development of an electrical charge on a crystal when pressure is applied to its surface. This is only possible in substances that crystallize with the requiste degree of asymmetry and are anisotropic.

After the French engineer and physicist Charles Augustin Coulomb [1736-1806] speculated that electricity might be produced by means of pressure, in 1817 the great French mineralogist René Just Haüy[570] and in 1820 Antoine César Becquerel [1788-1878][571] performed numerous experiments in which they reported certain crystals showed electrical effects when compressed. However, reviewing their findings it is not clear that they saw pressure induced electrical current because they reported the phenomena in such non-peizoelectric crystals as calcite. This suggests that they were chiefly observing contact electricity.

Credit for the prize winning discovery of this physical property is therefore awarded to the brothers Pierre[572] and Paul-Jacques Curie[573] who established the relationship between this property and a crystal's symmetry.[574] Their initial studies observed the

[569] Further historical information may be found in: W.G. Cady., *Piezoelectricity*. New York, McMillian and Co., 1946. • A. Ballato., "Piezoelectricity: old effects and new applications," *IEEE Ultrasonics Transactions, Ferroelectric Frequency Control*, **42** (1995), pp. 916-926. • *ibid.*, "Piezoelectricity: history and new thrusts," *IEEE Ultrasonics Symposium*, **1** (1996), pp. 575-583. • Shaul Katzir., "The Discovery of the Piezoelectric Effect," *Archive for History of Exact Sciences*, **57** (2003), 61-91. • W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

[570] Rene Just Haüy., "Sur l'électricité produite dans les minéraux à l'aide de la pression," *Paris, Museum Histoire Naturelle Mémoirs*, **3** (1817), pp. 223-228. ; *ibid.*, "Nouvelles observations sur la faculté conservatrice de l'électricité acquise à l'aide du frottement," *Journal de Physique*, **89** (1819), 455-462.

[571] A.C. Becquerel., "Sur le développement de l'électricité dans les corps par la pression et la dilatation," *Paris, Soc. Philom. Bull.*, (1820), p. 149-155.; *ibid.*, "Sur le développement de l'électricité par la pression," *Annals de Chimie*, **22** (1823), p. 5-34.

[572] Pierre Curie (Born: Paris, France, 15 May 1859; Died: Paris, France, 19 April 1906) After attending the Sorbonne, where he served as preparator in physics and received the master's degree and later the degree of doctor of science, Curie was appointed to a professorship in the Municipal School of Physics and Chemistry in Paris in 1895, and in the same year he married Marie Sklodowska. In 1900 he became a professor at the Sorbonne. In addition to his famous work on radioactivity in collaboration with Mme. Curie and on piezoelectric and other properties of dielectrics with his brother, his researches included the principles of symmetry, the design of various measuring instruments of great delicacy, and especially the effects of temperature on magnetism. [DSB].

[573] Paul-Jacques Curie (Born: Paris, France, 1855; Died: 1941) At the age of twenty he became preparator of chemistry courses in the School of Pharmacy and later preparator in the laboratory of mineralogy under Friedel, at the Sorbonne. He was associated with Friedel in a series of publications on pyroelectricity. It was in this laboratory that he and Pierre Curie discovered piezoelectricity in 1880. For this discovery the two brothers were awarded the Planté prize in 1895. In 1893 Jacques Curie became head lecturer in mineralogy at the University of Montpelier. His last work in physics was his determination of the piezoelectric constant of quartz in 1910. Suffering from a serious deafness, he retired in 1925. [Cady, *Piezoelectricity*, 1946, p. ??].

[574] Jacques Curie and Pierre Curie., "Developpement, par pression, de l'electricite polaire dans les cristaux

phenomena in a number of substances including halite, boracite, sphalerite, tourmaline, quartz, calamine, topaz, tartaric acid, cane sugar and Rochelle salt. In later research, the Curies described the effect in other crystals, the first attempt at a quantitative measurement of the phenomena in quartz and tourmaline, and the practical applications of the crystals. In 1881 shortly after the Curies announced their discovery, Gabriel Lippman [1845-1921] predicted that applying an electrical field in the appropiate directions along a piezoelectric crystal would cause the reverse effect and produce changes in the dimensions of the crystal.[575] This converse effect was not foreseen by the Curies, but in 1881 they quickly confirmed the theory showing that the piezoelectric coefficient of quartz had the same value for the converse of the direct effect.[576]

In scientific circles great interest was initially attached to this discovery. The German chemist Wilhelm Gottlieb Hankel [1814-1899], who had done considerable pyroelectrical research did not believe as the Curies did in a one-to-one relationship between the electrical effects of thermal and mechanical deformation. Instead, he believed that this new effect had special laws of its own and proposed in 1881 the name "piezoelectricity" (Greek *piezo-*="to press") to distinguish it. This term was quickly adopted by everyone including the Curies.

Perhaps the greatest researcher in the piezoelectric effect was Woldemar Voigt[577] who by combining elements of crystal symmetry with symmetry elements of elastic tenosors and electric vectors showed in 1890 in which of the 32 crystal classes piezoelectric effects might occur. For each of these classes Voigt then derives which of the possible 18 piezoelectric coefficients might have non-zero values.[578] Voigt continued his research and fully explored this study in his *Lehrbuch der Kristallphysik* that appeared in 1910 and which was for many years the standard reference in its subject. However, this was an exception.

For several decades after its discovery the piezoelectrical effect was a mere curiousity, unmentioned in many textbooks and regulated to being the subject of several obscure doctoral theses; however, some practical applications became apparent with the start of World War I. In France, the physicist Paul Langevin [1872-1946] developed in 1918 the idea of electrically exciting quartz plates to serve as emitters and later as receivers of under water high-frequency sound waves. The "echo method" (later to be called sonar) has proven an invaluable aid in locating immersed objects and exploring the ocean depths.[579] Because of this work Langevin is justly called a founder of the science of ultrasonics.

Walter Guyton Cady [1874-1974] used the vibration of crystal plates under the influence of an alternating electrical field to invent in 1918 the piezoelectric resonator. Producing high-frequency vibrations this device that has at its core a crystal of quartz or tourmaline has many practical applications and may be found in quartz clocks and watches, frequency controllers for radio, television and computers, and ultrasonic wave generation in gases, liquids

hemiedres a faces inclinees," *C.R. Acad. Sci.*, **91** (1880a), 294-295. • *ibid.*., "Sur l'electricite polaire dans les cristaux hemiedres a faces inclinees," *C.R. Acad. Sci.*, **91** (1880b), 383-387.

[575] Lippmann, G., "Principe de la conservation de l'electricite," *Ann. Chim. (Paris)*, **24** (1881), 145-178.

[576] Jacques Curie and Pierre Curie., "Contractions et dilations produites par des tensions electriques dans les cristaux hemiedres a faces inclinees," *C.R. Acad. Sci.*, **93** (1881), 1137-1140.

[577] Woldemar Voigt (Born: 1850; Died: Göttingen, Germany, 1919) Voigt studied under F. Neumann, to whose influence his interest in crystal physics was due. In 1875 he became Ausserordentlicher Professor of physics at Konigsberg, and in 1883 professor of theoretical physics at Gottingen, where he remained until his death. He served twice as Rektor of the University of Gottingen. Besides his monumental work in the physics of crystals, he made notable contributions in elasticity, thermodynamics, and magnetoand electro-optics. [*Physik. Zeitschrift*, **21** (1920), pp. 81-82 by C. Runge; DSB].

[578] W. Voigt., "Ueber die innere Reibung der festen Korper, insbesondere der Krystalle," *Abh. K. Ges. Wiss. Göttingen*, **36** (1890a), 1-47. • *ibid.*., "Allgemeine Theorie der piezo- and pyroelectrischen Erscheinungen an Krystallen," *Abh. K.. Ges. Wiss. Göttingen*, **36** (1890b), 47-99.

[579] P. Langevin., Procédés et appareils pour la production de signaux sous-marins dirigés et pour la localisation à distance d'obstacles sous-marins." *Brevet Français*, no. 502.913 (29 May 1916). • *ibid.*., "Procédés et appareils d'emission et de reception des ondes elastiques sous-marines a l'aide des proprietes piezo-electriques du quartz." *Brevet Français*, no. 505,703, 17 September 1918.

and solids.

Early attempts at deriving an atomic theory to explain piezoelectricity were described by the Curries,[580] Riecke,[581] Voigt,[582] and Lord Kelvin.[583] The renowned physicist Max Born provided the most rigorous study when he included the dielectric, pyroelectric and piezoelectric effects within his general theory of lattice dynamics. He applied the theory to a small series of cubic lattices, and in 1920, together with Elisabeth Bormann, he published the first theoretical calculation of the piezoelectric constant of sphalerite.[584]

### 5.7.4 Thermoelectricity[585]

**REWORK:** Thermoelectricity is the direct conversion of heat into electric energy, or vice versa. The term is generally restricted to the irreversible conversion of electricity into heat described by the English physicist James P. Joule and to three reversible effects named for Seebeck, Peltier, and Thomson, their respective discoverers. In minerlogy it is applied to the contact of two unlike metals which in general results in electrifying one of them positively and the other negatively. If, further, the point of contact is heated while the other parts, connected with a wire, are kept cool, a continuous current of electricity will be produced.

The earliest observation on thermoelectricity in crystals relates to the sulfides of cobalt and iron. Hankel showed that when certain external faces were developed the crystals were thermoelectrically positive relative to copper, whereas with other facial forms they were negative.[586] This peculiarity remained unexplained until recently when it was related to certain departures from the ideal chemical composition.

In 1843, Gustav Rose and ——— introduced the concept of electrical axes in crystals, which possess asymmetric ends on the crystal terminations. In ——— the well known physicist A. Kundt [1839-1894] invented a visual representation of the electrical current. By dusting the sample with yellow powder of sulfur and the red dust of minium near the positive and negative ends of the electrical axes, the flow of current would cause the particles to be carried along through electrostatic processes. The method was successfully employed by the Russian Kolepko [1856-1946] in his study of the polar electricity of quartz with respect to its crystallographic symmetry (1884).[587]

In 1850 Svanberg used the trigonal crystals crystals of bismuth and of antimony to find the variation of the effect with direction in the crystal.[588] These crystals both of which cleave very readily parallel to the basal plane, parallel to the cleavage direction and perpendicular to the trigonal and optic axis behaved thermo-electrically more positively, and parallel to the axis more negatively, than any other of these metals. Also the thermo-electric current afforded by the two kinds of bismuth, or by the two differently cut antimony, was of considerable strength.

Franz,[589]

Thomson put forward a mechanical theory of thermoelectric currents in crystalline

[580] See previous citations.

[581] E. Riecke., "Zur Molecularttheorie der piezoelectrischen and pyroelectrischen Erscheinungen," *Göttinger Nachr.*, 1893, pp. 191-202.

[582] Voigt, W., "Beitrage zur molekularen Theorie der Piezoelectricitat," *Göttinger. Nachr.*, 1893, pp. 649-671.

[583] William Thomson Kelvin, (*Lord*)., "Théorie de la pyro-électricité et de la piézo-électricité," *Paris, C.R. Acad. Sci.*, **117** (1893), pp. 463-472. • *ibid.*., "On the piezoelectric property of quartz," *Philosphical Magazine*, **36** (1893), 331-340.

[584] Max Born and E. Bormann., "Zur Gittertheorie der Zinkblende," *Annals der Physik*, **62** (1920), pp. 218-246.

[585] Further historical information may be found in: Bernard S. Finn., "History of Thermoelectricity," *Advances in Electronics and Electronic Physics*, **50** (1980), p. 175-240. [A detailed discussion of experimental and theoretical work, based on Ph.D. dissertation.] • W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

[586] W.G. Hankel., "Ueber die Thermo-Elektricität der Metalle und metallischen Mineralien (Erze)," *Poggendorff Ann. Phys.*, **62** (1844), p. 197-207.

[587] Shafranovskii, *Istoriia kristallografii XIX vek*, 1980, p. 209.

[588] Svanberg, J., "Expériences sur le pouvoir thermo-électrique du bismuth et de l'antimoine cristallisés," *C. R. Acad. Sci.*, **31** (1850), p. 250-252.

[589] Pogg. Ann., 1851, 83, 374, and 1852, 85, 388.

solids.[590]

Marbach.[591] Marbach observed a very remarkable fact with respect to iron pyrites, FeS2, which crystallises in the cubic class. It is often found in actual experiments that the rules already stated are apparently materially departed from, owing to the altogether unexpectedly large disturbing effect of minute quantities of foreign enclosures, which are so common in mineral crystals, and which often generate a current in the opposite direction to that produced by the pure substance of the crystal. Even more pronounced, however, are the apparent deviations when a mineral exists in two forms like quartz, currents of opposite characters and of equal strengths being generated by the two varieties.

In 1864 Bunsen showed that this subject was important to mineralogy, that the natural metallic sulphides stand farther off in the series than bismuth and antimony, and consequently by them a higher electromotive force is produced.[592]

The thermo-electrical relations of a large number of minerals were determined by Walther Flight [1845?-1885].

It was early observed that some minerals have varieties which are both + and - . Rose attempted to establish a relation between the positive and negative pyritohedral forms of pyrite and cobaltite, and the positive or negative thermoelectrical character.[593] Later investigations by Schrauf[594] and Dana[595] have shown, however, that the same peculiarity belongs also to glaucodot, tetradymite, skuttemdite, danaite, and other minerals, and it is demonstrated by them that it cannot be dependent upon crystalline form, but rather upon chemical composition.

Friedel.[596]

In 1888 Bäckström carried out a thorough study on hematite.[597] Bäckström studied the thermo-electricity of haematite with the same magnificent specimens as were used for the electrical conductivity. Two boxes constructed of copper foil were attached to two wooden discs, the upper of which was movable by means of a screw, and the crystal bar was laid between the boxes, good contact being attained by means of the screw. Through the upper box steam at 100° was blown, and through the lower box ordinary cold water was led, in which a thermometer was immers.d. To each box a copper wire was soldered, and connected to a Lippmann capillary electrometer as soon as the boxes had attained a constant temperature, the thermo-electric power being directly measured in volts.

The Peltier effect was also discussed (Liebisch, 1889).[598]

Perrot,[599] Perrot's researches are also of special interest, as he had at his disposal some large and very homogeneous prisms of bismuth, which is the metal most easily obtained in good and sufficiently large crystals It will be remembered that the crystals of bismuth are trigonal, with basal plane cleavage. But the metal has a very low point of fusion, so that it has only been possible to study its thermo-electrical properties up to 100° C.

During the years 1847 to 1850 Sénarmont [1808-1850] established the relationship between the optical properties of crystals and their thermal conductivity. Covering the sample crystal face to be investigate with a thin flat layer of wax and then touching the end of a heated silver wire to a point on that surface, circular or elliptical pits of melting wax were obtained elsewhere on the face that depended

[590] W. Thomson., "A mechanical theory of thermo-electric currents in crystalline solids," *Math. Phys. Pap.*, **1** (1854), 324-325. • *ibid.*., "On thermo-electric currents in linear conductors of crystalline substances," *Math. Phys. Pap.*, **1** (1854), 266-291. • *ibid.*., "On thermo-electricity in crystalline metals, and in metals in a state of mechanical strain," *Math. Phys. Pap.*, **1** (1854), 467-468. • *ibid.*., "On the dynamical theory of heat. Part V. Thermo-electric currents," *Trans. R. Soc. Edinburgh*, **21** (1854), 123-171.

[591] Compt. rend., 1857, 45, 705.

[592] Bunsen. Pogg. Ann., 123, 505, 1864.

[593] Rose. Pyrite and cobaltite. Pogg. Ann., 142, 1, 1871.

[594] Schrauf, Ber. Ak. Wien, 69 (1), 142, 1874.

[595] E. S. Dana, Am. J. Sc, 8, 255, 1874.

[596] Ann. Ch. Phys., 17, 79, 1869; C. R., 78, 508, 1874.

[597] Of vers. K. Vetensk.- Akad. Fork, 1888, No. 8, 553.

[598] Liebisch, T., "Ueber thermoelektrische Ströme in Krystallen," *Nachr. Ges. Wiss. Göttingen*, 1889, pp. 531-535.

[599] Arch. Sci. phys. et nat. Genève, 1898, 6, 105 and 220

on the planar symmetry of the crystal. Subsequent investigations were made by Viktor von Lang (1866) and E. de Jannetez (1873). As a result it was shown that thermal conductivity in a crystal may be expressed in the general case as a 3-dimensional ellipsoid.[600] For cubic crystals the surface or shape of thermal conductivity takes the form of a sphere, while for optically uniaxial crystals it is an ellipsoide. Orienting these surfaces in crystals corresponds to orienting optical indicatrices.[601]

Investigations into the expansion of crystals by heating were conducted in 1865 by the French physicist A. Fizeau [1819-1896]. He found that for typical crystals the amount of expansion in 3-dimensions may be expressed as the surface area of the ellipsoides of revolution.[602]

### 5.7.5 Dielectric Property[603]

**REWORK:** In the case of non-conducting crystals, instead of variation of conductivity, there is measured the variation in the dielectric constant. This is the measure of insulation or lack of conductivity, and the ability of the mineral to hold an electric charge on its surface.

Wiedemann[604]

Senarmont[605] **28** (1850), p. 257.

In 1851 the first experiments on the behavior of crystals in an electric field were carried out by Knoblauch in a manner similar to that used for the study of magnetic properties.[606] The conductivity of the crystals, both over the surface and through the body of the crystal made these experiments unreliable.

In 1876 Root avoided some of these difficulties by employing a rapidly alternating field between parallel plates.[607]

Hopkinson gave a list of dielectrical constants of various crystals and glass.[608]

In 1893 Pockels gave an account of the abnormally large piezoelectric constants of Rochelle salt ($C_4H_4KNaO_6 \bullet 2H_2O$).[609]

In 1919, R. Fellinger determined the dielectric values for the axial directions of the precious stones, including topaz, beryl, ruby, and sapphire.[610]

In 1920 Valasek found the same kind of hysteresis loop, when plotting electric polarization versus the applied electric field, as was well known in ferromagnetism.[611]

The dielectric constant in the ferroelectric phase of any given crystals is usually several orders of magnitude greater than that of nonferroelectric materials. This has important applications in the manufacture of capacitors. The dielectric loss in ferroelectric materials is relatively high and this to some extent limits their usefulness.

Some dielectric materials can retain their electric polarization for relatively long periods and in this condition are called electrets. Examples of this are magnesium titanite and some forms of crystalline sulfur. In such materials the electric dipole is the analogue of the magnetic dipole. In most dielectrics the charge leaks away in hours or minutes, so that it is possible to obtain electrets with only a small number of materials.

## 5.8 Magnetism[612]

[600] Shafranovskii, *Istoriia kristallografii XIX vek*, 1980, p. 208-209.

[601] Shafranovskii, *Istoriia kristallografii XIX vek*, 1980, p. 208.

[602] Shafranovskii, *Istoriia kristallografii XIX vek*, 1980, p. 208-209.

[603] Further historical information may be found in: H.D. Megaw., *Ferroelectricity in crystals*. London, Methuen, 1957. E.A.H. Tutton., *Crystallography*. London, 1922, **2**, p. 1390-1394.

[604] Poggendorffs Annalen, **76** (1849), p. 404 and **77** (1850), p. 534.

[605] Ann. Chim. Phys.

[606] H. Knoblauch., "Ueber das Verhalten krystallisierter Körper zweischen elektrischen Polen," *Poggendorff Ann. Phys.*, **83** (1851), 289-299.

[607] E. Root., "Zur Kenntniss der dielektrischen Polarisation," *Poggendorff Ann. Phys.*, **158** (1876), p. 1-35, 425-461.

[608] Phil. Mag., **13** (1882), p. 242.

[609] F.K. Pockels., "Ueber den Einfluss des electrostatischen Feldes auf das optische Verhalten piezoelektrischer Krystalle," *Abh. Göttingen Ges. Wiss.*, **39** (1893), 1-204.

[610] Fellinger, Annals de Physique, 1919 **60**, p. 181.

[611] J. Valasek., "Piezoelectric and allied phenomena in rochelle salt," *Phys. Rev.*, **15** (1920), 537-538.

[612] Further historical information may be found in: Edmund Hoppe., *Geschichte der Physik*, p. 337-344. • Stephen T. Keith and Pierre Quédec., "Magnetism and magnetic materials" (pp. 359-442) in: Lillian Hoddeson, ed., *Out of the Crystal Maze: Chapters from the History of Solid State Physics*. New York, Oxford University Press,

**REWORK:** A few minerals in their natural state are capable of being attracted by a strong steel magnet; they are said to be magnetic. This is conspicuously true of magnetite, the magnetic oxide of iron; also of pyrrhotite or magnetic pyrites, and of some varieties of native platinum (especially the variety called iron-platinum).

A number of other minerals, as hematite, franklinite, etc., are in some cases attracted by a steel magnet, but probably in most if not all cases because of admixed magnetite. Occasional varieties of the three minerals mentioned above, as the lodestone variety of magnetite, exhibit themselves the attracting power and polarity of a true magnet. They are then called natural magnets. In such cases the magnetic polarity has probably been derived from the inductive action of the earth, which is itself a huge magnet.

In a very strong magnetic field, as that between the poles of a very powerful electromagnet, all minerals, as indeed all other substances, are influenced by the magnetic force. According to their behavior they are divided into two classes, the paramagnetic and diamagnetic; those of the former appear to be attracted, those of the latter to be repelled. Iron, cobalt, nickel, manganese, platinum are paramagnetic; silver, copper, bismuth are diamagnetic. Among minerals compounds of iron are paramagnetic, as siderite, also diopside; further, beryl, dioptase. Diamagnetic species include calcite, zircon, wulfenite, etc.

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The magnetic oxide of iron, magnetite, was known and used by the Greeks and Romans. In the 13th century the basic properties of magnetic poles were under-stood.[613] Up to the 19th century crystals were regarded either as magnetic or nonmagnetic. The magnetic crystals are now called ferromagnetic to distinguish them from the several other kinds which have since been discovered.

1728: Charles-François De Cisternai Du Fay wrote on magnetism ( 1728).[614]

1826: Poisson gave a theory of magnetism as applied to crystals and predicted the behaviour of crystals in a magnetic field which was verified by Plücker in 1847.[615] He determined the magnetic attraction of a number of substances compared with iron taken as 100,000. For example, for magnetite he obtained 40,227; for hematite, crystallized, 533, massive, 134; limonite, 71; pyrite, 150.

He studied quartz, zircon, beryl, vesuvianite and corundum, and related the reaction of the crystal to a magnetic field to its symmetry. All these crystals were repelled from a strong field, unlike the ferromagnetic crystals. They were therefore called diamagnetic.

1850: Several investigations were carried out by Plücker & Beer using torsion balances to measure the small forces involved in most observations.[616] Not only were some crystals repelled from a strong field but there were others which were slightly attracted. These were called paramagnetic. By the end of the 19th century the three types of crystal ferro-, dia- and paramagnetic, were well established and successful theories had related dia- and paramagnetic crystals to their crystal symmetry.

1896: Weiss studied ferromagnetic properties who explained the hysteresis by supposing the atoms to have permanent magnetic poles which are normally randomly arranged but become more and more parallel under the influence of an applied magnetic field. On removing the field the mutual effect of the parallel dipoles tends to maintain the magnetized state. He further postulated that there were domains within which all the atomic dipoles were simi-

1992. • P.F. Mottelay., *Bibliographical history of electricity & magnetism chronologically arranged.* New York, 1922. xx, 673 p., index. [Reprinted, Mansfield Centre, Martino Fine Books, 1993. An essential bibliography of electrical and magnetic phenomena from 2637 B.C. to 1821 A.D. Contains at the end, biographical notes on the people mentioned.] • W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

[613] E. Wiedemann., "Beiträge 2, Über Magnetismus," *Sitzungsberichte der Physikalisch-medizinischen Sozietät in Erlangen*, **36** (1904), 322-331.

[614] ????? C.-F. Du Fay., "Observations sur quelques expériences de l'aimant," 1728, p. 355-369.

[615] Pogg. Ann., 74, 343, 1848.

[616] Plücker and Beer. Pogg. Ann., 81, 115, 1850; 82, 42, 1852. and Pogg. Ann., 72, 315, 1847; 76, 576, 1849; 77, 447, 1849; 78, 427, 1849; 86, 1, 1852.

larly orientated and that the N-S axis could be differently orientated in neighbouring domains. This theory was widely accepted but no physical proof of the existence of these domains was given until 1931 with the theory of Bitter.

The magnetic properties of minerals became a subject of special interest in the middle of the 19th century. In a paper on the polar magnetism of minerals and rocks (1849), Achille Delesse noted that many non-ferrous minerals are magnetic and that, in crystals, the distribution of the magnetic poles is unrelated to the crystallographic axes.[617] Studying the action of magnetism on different substances, Edmond Becquerel was led to introduce the effects of the surrounding medium into the explanation of magnetic phenomena.

Faraday studied magnetism ...[618]

Lord Kelvin also was interested in the subject.[619]

Knoblauch and Tyndall studied damagnetism in crystallization. [620]

1879: Rowland and Jacques. Bismuth, Calcite. Am. J. Sc, 18, 360, 1879. Tumlirz. Quartz. Wied. Ann., 27, 133, 1886.

1883: Stenger. Calcite. Wied. Ann., 20, 304, 1883; 35, 331, 1888.

1887: Koenig. Wied. Ann., 31, 273, 1887.

Another reference ...[621]

## 5.9 Elasticity[622]

**REWORK:** Elasticity, or the ability of a crystal to stretch when pulled was also studied. Some minerals (e.g. a sheet of mica) are highly elastic, springing back to their original shape after being bent. Others (e.g. talc) may be readily bent, but do not return to their original form when released; these are said to be pliable or flexible. Sectile minerals (e.g. chlorargyrite) may be cut with a knife without being fractured: related characters are malleability (e.g. argentite) and ductility (e.g. silver). The tenacity, or degree of frangibility of different minerals varies widely: they may be brittle, tough, soft or friable. The fractured surface produced when a mineral is broken is called the " fracture," and the kind of fracture is often of determinative value; descriptive terms are: conchoidal (e.g. quartz, which may often be recognized by its glassy conchoidal fracture), sub-conchoidal, uneven, even, splintery (e.g. jade), hackly or with short sharp points (e.g. copper), &c.

General principals of te theory of the elasticity of solid bodies were developed in the 1820s by the mathmeticaians and physicists: M. Mauleg [1785-1836], S.D. Poisson [1781-1840], and O.L. Cauchy [1789-1857]. Later F. Neumann and his student G. Voigt gave an expanded study of elasticity in crystals. From their conclusion they demonstrated their existed a coefficient of elasticity in crystals. For a cubic crystal this has identical maximums and minimums in the 3 dirctions of the axes of symmetry. Plotting the coeffienent of the faces of they crystal shows the geometric shape of the property. Those surfaces that correspond to the eight faces of an octahedron correspond to a circle.[623]

**[Get images from Shafranovskii,** *Istoriia kristallografii XIX vek***, 1980.]**

1827: Navier developed a theory based on the mutual action of a regular arrangement of particles was advanced for an isotropic body.

1823: Cauchy studied noncubic bodies.

1829: Poisson also studied it.

1837: Green introduced the limitation that the force between any two elements of a crystal,

[617]

[618] Faraday. Phil. Trans., 1849-1857, and Experimental Researches, Series XXII, XXVI, XXX.

[619] W. Thomson (Lord Kelvin). Theory of Magnetic Induction. Brit. Assoc, 1850, pt. 2, 23; Phil. Mag., 1, 177, 1851, etc. Reprint of Papers on Electrostatics and Magnetism, 1872.

[620] Tyndall. Phil. Mag., 2, 165, 1851; 10, 153, 257, 1855; 11, 125, 1856; Phil. Trans., 1855, 1. Researches on diamagnetism and magne-crystallic action. London, 1870. and Knoblauch and Tyndall. Pogg. Ann., 79, 233; 81, 481, 1850 (Phil. Mag., 36, 37, 1850).

[621] Alfred Still., *Soul of lodestone; the background of magnetical science*. New York, Toronto, Murray Hill Books, Inc., 1946. x, 233 p. [History of magnetism.; Written as a companion volume to the authors, *Soul of Amber*.]

[622] Further historical information may be found in: *Dana's Textbook*, p. 195. • Tutton, *Crystallography*, London, 1922, **1**, p. ??. • W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

[623] Shafranovskii, *Istoriia kristallografii XIX vek*, 1980, p. 209-211.

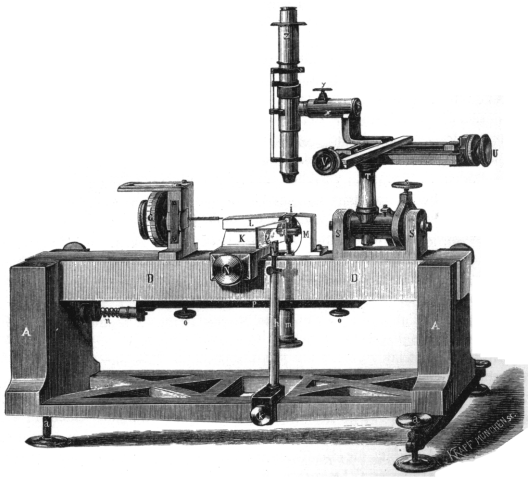
however small, must lie along the line joining their centres.

1887: Röntgen & Schneider made measurements of the cubic compressibility of NaCl and KCl.

1874: Baumgarten made measurements based on bending bars of calcite as did Voigt.

1874: Untersuchung der Elasticitätsverhältnisse des Steinsalzes, Inaugural dissertation von Woldemar Voigt (1874).

1876: Voigt made measurement based on twisting bars or rods. For a number of cubic crystals all three elastic constants (or moduli) were thus determined. Voigt continued these investigations over the next 13 years and determined the properties of crystals of hexagonal, trigonal and orthorhombic symmetry (Voigt, 1888).



Elasticity Tester (c1900)

## 6.0 Chemical Mineralogy[624]

Minerals are at their core naturally occurring chemical compounds, and the greatest strides in understanding them occurred in conjunctions with developments in chemistry. In fact some of the earliest knowledge of chemistry comes from the methods used in resting useful metals from their host rock, as happened in antiquity during the Copper, Bronze, and Iron ages. Additionally, the compounds most readily available to early chemists were minerals, which therefore made them ripe for study.

### 6.1 Technological Background

**REWORK:** The technological arts, particularly assaying and metallurgy, made significant contributions to the advance of chemistry. However, the early miners and assayers were largely illiterate and left no documentation—the techniques they used being passed by word of mouth from worker to worker. But in sixteenth century Europe, when mining had become an important economic activity, there appeared books dealing with these subjects. These texts are valuable in showing the state of the technical arts at the time.

The books vary from the utilitarian "do it yourself" booklets to complete treatises. They are all characterized by a practical approach, which is not suprising having been written by practical men. Little or no theory can be found in their pages, the object being to teach workable techniques. This was highlighted early in the century by the appearance of the *Ein nutzlich bergbuchlēy* (Little Book of Ores) that was frequently

[624] Further historical information may be found in: Johann Friedrich Gmelin., *Geschichte der Chemie*. Göttingen, 1797-9. 3 vols. viii, 777 p.; [2], 790 p.; [4], 1288, [96] p. [Reprinted, Hildesheim, Georg Olms Verlagsbuchhandlung, 1965; An early comprehensive history of chemistry, written only a few decades after Lavoisier's contributions, by a leading scientist of the time.] • Hermann Kopp., *Geschichte der Chemie*. Braunschweig, Friedrich Vieweg und Sohn, 1843-7. 4 vols., 4 portraits. [Comprehensive history of chemistry to 1840.] • A.A. Manten., "Historical foundations of chemical geology and geochemistry," *Chemical Geology*, **1** (1966), p. 5-31. • Seymour H. Mauskopf., "Crystals and compounds: molecular structure and composition in nineteenth-century French science," *Transactions of the American Philosophical Society*, **66** (1976), p. 1-82. • Robert P. Multhauf., "The beginning of mineralogical chemistry," *Isis*, **49** (1958), p. 50-53. • David R. Oldroyd., *From Parcelsus to Haüy: the developement of mineralogy in its relation to chemistry. Ph.D. Dissertation*. University of New South Wales (Australia), 1975. • James R. Partington., *A history of chemistry*. London, Macmillian, 1961-70. Vol. 1, pt. 1, 2-4. xlv, 370 p.; xxiv, 795 p.; xxiii, 854 p.; xxxi, 1007 p. [No more published. Indispensable standard reference in the history of chemistry.] • Theodore M. Porter., "The promotion of mining and the advancement of science: The chemical revolution of mineralogy," *Annals of Science*, **38** (1981), p. 543-570. • J.M. Stillman., *The story of early chemistry*. New York & London, D. Appleton and Company, 1924. xiii, [1], 566 p., biblio., index. • F. Szabadváry., *History of analytical chemistry*. Translated by Gyula Svehla. Oxford, London, etc., Pergamon Press, 1966. ix, [1], 418 p., illus., notes, indexes.

reprinted. It deals primarily with the location of ores. Of greater significance to chemistry were the *Probierbuchlein* that began to appear around 1510. These small books gave the techniques used to assay the metal content of ores, but also discuss balances and weights, sampling techniques, the touchstone, furnaces and crucibles, cupellation, the separation of gold, silver, and copper, cementation, recovery of precious metals from scrap, and other miscellaneous operations on silver and gold.

Printing was not even a century old when in 1540 the first work on metallurgical science appeared. The *De la Pirotechnia* written by Vannuccio Biringuccio [1480-1537] was one of the first technological treatises ever printed. Biringuccio acquired his knowledge of metallurgy by traveling extensively through Italy and Germany and reviewing the mine and metal works he encountered. He was interested in the practical aspects of metal technology. His book shows a man amazingly lacking of superstitious believes, and the contempt he holds for alchemy marks him as one of the first real chemists.

A comprehensive treatise on metallurgy, the *Pirotechnia* is divided into ten books. Book I discusses the treatment of the ores of gold and silver, copper, lead, tin, and iron. It describes their location, surface markings, and recovery. Book II is devoted to mercury, sulfur, antimony, alum, arsenic, salts, and borax. In Book III cupellation, roasting, and testing are treated. The preparation and use of aqua fortis in parting is found in Book IV. Alloys, casting, furnaces, and molds are the subjects of Books V through VIII. The last two books are of chemical interest, containing details on sublimation, distillation, pyrotechny, and allied subjects. The first description of the recovery of silver by amalgamation is found in Book X. The method for the preparation of saltpeter in the Book X is the earliest complete account. Agricola's process was taken from this source, as was his description of the distillation of mercury and sulfur, glass and steel manufacture, and the preparation of alum and vitriol.

The *Pirotechnia* appeared in seven Italian and three French editions and was apparently widely used. Its unattractive format and poor illustrations, as well as to the author's crude literary style, and it never appearing in a Latin edition all contributed to its influence being less than it could have been. In fact, its principal influence comes mainly from later metallurgical publications that reference Biringuccio's work.

Georgius Agricola's *De Re metallica* was published posthumously in 1556. It is a work that describes in a very lucid manner the various metallurgical and mining procedures of the time and is richly illustrated with hundreds of woodcuts. Although Agricola borrowed liberally from previous authors, sometimes with only minor acknowledgement, he also includes much of his own rich experience that he accumulated observing the mining operations of Saxony. Agricola deals factually with his material giving complete and detailed accounts of problems and solutions in mining and metallurgy. For a long time it remained the standard work in its field, with a German translation appearing in 1557, an Italian in 1563, and numerous reprints published. Like the *Pirotechnia*, it contains sections on assaying, salt preparation, niter, and related subjects, in addition to a good discussion of general metallurgy. Agricola's contributions to chemistry were of lesser influence and are largely confined to Book XII of the *De re Metallica*. It is unquestionable, however, that the sharp clarity and practical focus of his accounts had a wide influence on the development of chemical science.

Another major work of high quality was the *Beschreibung Allerfürnemisten Mineralischen Ertzt vnnd Berckwercksarten* written by Lazarus Ercker [c1530-1594] and published in Prague in 1574. It is a systematic review of the methods used in obtaining, refining, and testing the alloys and minerals of gold, silver, copper, antimony, tin, mercury, and lead. He covers the preparation of acids, salts, and other useful compounds, as well as describing and illustrating the apparatus. As inspector general of the mines of the Holy Roman Empire, Ercker was able to travel extensively and observe mining and metallurgical operations of all types, and his work is based on his own practical experience. It covers much the same ground as

Agricola, but Ercker gives more emphasis to assay methods. Like the treatises before him he emphasises the practical aspects of the operation, and in particular, Ercker discusses how to refine precious metals to remove impurities like lead and copper. Other books on metallurgy appeared, but none of them were as innovative as the these classic works, which suggests the technology was not advancing much. This would remain the condition until chemistry developed to a point where it could impact practical technology.

The assay methods described in the works of Biringuccio, Agricola, and Ercker are the first group of quantitative tests in chemistry. The techniques outlined imitate the overall smelting process and their objective was to accurately determine the amount of gold and silver that could be recovered from an ore rather than the exact quantity of metal present. This approach could also be used to figure out purity of the metal used in coins and jewelry. It was a useful and practical approach to chemistry that the alchemy of the time was lacking.

Apparatus used in the assayors office of the time included muffle furnaces and balances, with the necessary compliment of items like weights, cupels, crucibles, flasks, and tongs. The best balances were well crafted devices that were sensitive to 0.1 mg and were encased in a box with a beamlifting apparatus to protect the knife edge of the scale. Weights were not of standard sizes but represented fractions of the amounts used in large scale operations. Using these insturments and much skill, the assayor of the time recognized antimony, arsenic, bismuth, and zinc as metals distinct from the seven known in antiquity. Previously, these four had been thought of as stong alloys of one of the known metals with other materials like lead and mercury.

Technological books of the time also treated other subjects like the making of glass, pottery, gunpowder, salts, and acids. Some of these arts were reexamined in light of the practical changes being introduced. Bernard Palissy [c1510-1589] experimented with clays and enamels used in pottery and developed a distinctive glazed stoneware that became popular with the French aristrocracy. In 1540, Christoph Schirer of Saxony introduced the use of cobalt compounds in the production of blue glass.[625] The element cobalt was itself was not recognized for another two centuries, although miners had encountered diffculty recovering copper from it refractory ores using standard procedures. Superstition caused the miners to believe such material was bewitched by the gnomes or Kobalds of the mountains. Nickel was causing similar problems, and was therefore referred to as Kupfernickel, or "Old Nick's Copper."

Substantial changes characterized the Renaissance with respect to the development of chemistry. The old alchemy transformed into the iatrochemistry founded by Theophrastus Bombastus von Hohenheim [1493-1541], who later called himself Paracelsus. Trained as a physician, he looked skeptically at the alchemists, but recognized that chemistry could play a useful role in medicine. He introduced iatrochemistry (from *iatro* meaning doctor in Greek), which marks the beginning of chemistry as an independent science. It turned attention away from alchemy and was a preeminent study throughout the sixteenth and seventeenth centuries. In his time, Paracelsus was a forceful presence, and his doctrines, which opposed the teachings of Galen and Avicenna, were viguroiusly championed or vehmently opposed by those that came after him.

Paracelsus works were published after his death. They are difficult to understand because of his obtuse and contradictory writing style. He shows belief in some of the alchemical concepts and incorporated mysticism into his writings. His direct contributions to chemistry are small, however, because he was a reformer of medicine. Yet his embracing of chemistry stimulated his followers to experiment, observe and ultimately think for themselves, which led to the overthrowing of long held learnings.

Much of Paracelsus' chemistry revolved around minerals, because they were the chemical compounds available. His *Ettliche Tractat Philippi Theophrasti Paracelsi ...*

[625] Stillman, *The story of early chemistry*, 1924, p. ??.

*von naturlichen Dingen* that first appeared in 1570 was prepared by Michael Toxites from previous publications and unpublished manuscript material. It is the fullest statement about Paracelsus' theory of minerals. His ideas about the origin of minerals are typical of the age. He believed that the seven planets influenced the production inside the earth of the various minerals. That the metals and minerals grew like roots within the earth, from congealing elemental water and comprise: (1) metals, (2) gems, (3) salts, (4) mineral springs, (5) silver and golden marcasites, (6) common stones, including marble, slate, alabaster and jasper, (7) sulfurous earths such as yellow (amber) and black (jet), and (8) coral, eagle-stone, most petrifications and 'lusta naturae' (sports of nature). The colors of gems are due to included metal impurities, thus the green of emerald comes from copper, the golden hue of carbuncle is due to gold, the red of ruby to iron, the blue of sapphire to silver, the white sapphire to tin, the hyacinth to mercury, and each in turn corresponding to particular planet. This is how each substance derives its medicinal virtue. Paracelsus' view on the generation of metals, stones and minerals owes much to the Arabic authors. He criticised the old theory that they were composed of only mercury and sulfur, believing that salt also entered into their composition. He recognized seven metals, corresponding with the planets, of both male and female types, thus iron was female while steel was male. He also recognized that many undiscovered metals might exist.

After its introduction, the iatrochemistry enjoyed a growing reputation, and became the dominate theory of chemistry.

Andreas Libavius (Andreas Libau) [1550-1616] wrote a number of books on medicine, alchemistry, and metallurgy, including his *Alchemia* (1597) that is considered the first textbook in chemistry. There is little doubt that Agricola's clear treatment of technological matters paved the way for the systematic approach of its subject taken in the *Alchymia*. Libavius was a teacher and physician of the later iatrochemical school, yet he was not a disciple of Paracelsus and vigorously denounced many of the latter's doctrines. Although the *Alchymia* includes some of Libavius's own discoveries, he contributed little original material to chemical theory. It is an attempt to systematize chemistry with a nomenclature that although strange, is clear and logical in its setting. The term 'alchemia' as invoked in the title of the book is used in much the same way the word chemistry is used today. Libavius divides his study into 'encheria' that deals with the methods, and 'chymia' that deals with the materials and their properties. 'Magisteria' encompasses the substance, its properties, and the forces that act upon it.

It was the practical approach taken in the *Alchemia* that was an innovation. The work remained for many decades the most important chemical book of its type, emboding a complete survey of the chemistry of the period and written in clear language with no attempt at obscurity. It was a basic text studied for chemical techniques by physicians and other scientists and included procedures for the preparation of zinc, lead nitrate, and anhydrous stannic chloride ("fuming liquor of Libavius"). His description of chemical apparatus is the most complete of its time. In many respects, Libavius' intelligent and practical discussions are modeled after the form of those found in Agricola's *De re Metallica*. They illustrate a transitional phase of chemical science being a mixture of alchemical and chemical learning, and thus among much rational material Libavius admits that the transmution of metals is possible. Like Paracelsus, Libviaus also wrote considerablly on mineralogical matters. His *Singulariarium Liber IV, quorum I et III de Metallis, Lapidibus et Fossilibus* (1599-1601) publishes lecture notes about the chemical nature of minerals, including separation techniques and analytical procedures.

A prominent disciple of Paracelsus was Jan Baptist Van Helmont [1577-1644]. An extended trip through Europe impressed him with the importance of chemistry. He gave up his medical interests and devoted the remainder of his life to chemical investigations. As a scientist, he strove to understand the chemistry that made the world around him. Van Helmont rejected the theories of the four

ancient elements and the three Paracelsian principles. Instead, he believed that air and water were the only basic elements. Since air, he believed, underwent no chemical changes, water was the basic element of all things. Van Helmont is said to represent the transition from alchemy to chemistry. He was the first to speculate correctly on the composition of complex chemical compounds, by reducing them to simpler bodies. He utilized quantitative procedures in his studies and showed for example, that when silver is dissolved in nitric acid, it does not loose its essence, but only changes form.

Some alchemists believed that the fact that metallic copper appeared when a piece of iron was placed in a blue vitriol solution was an example of a transmutation. Angelo Sala [1575-1640] who was the first to correctly recognize that the precipitation of copper form a solution of copper sulfate by the introduction of iron was not a transmutation of iron into copper, but a displacement of the copper from solution by iron.[626] Daniel Sennert [1572-1627] showed that gold could be precipitated from acids in which it had been dissolved, because gold atoms retained their fundamental essence inside the solution. He also postulated four kinds of atoms corresponding to the four elements, and suggested that substances of the second order were formed by the combination of primary atoms.

The Benedictine monk Basil Valentine of St. Peter of Erfurt, probably never existed.[627] The many works published under his name were probably authored by Johann Thölde of Hesse, who wrote them during the early years of the seventeenth century. Thölde claims to have found manuscripts which had been written by Basil Valentine in the first decades of the sixteenth century, but no mention of them is made prior to that time. Further evidence is contained in the works themselves which reference many chemical procedures that were known only a century later. Also, lengthy searches of the records of the monasteries in Germany and the archives at Rome by science historians have not turned up a monk by that name. Finally, the name Basil Valentine, or the "mighty king," has the sound of a pseudonym about it. Thölde probably invented the identity to secure prestige for his publications, and thus make their mystical and practical content even more appealing to their readership.

The works of Basil Valentine clearly show the influence of Paracelsus and contain no chemistry which was not known to Thölde and his contemporaries, although many of the methods described are written in the symbolic and imaginative language of alchemy. The *Triumph-Wagen des Antimonii* (The Triumphal Chariot of Antimony), one of the most important books from the fictious pen, first appeared in Leipzig in 1604. It contains much good genuine chemical knowledge, but makes extravagant claims for the effectivness of medical remedies containing antimony while giving clear directions for the preparation of the compounds. The work is generally cited as the first scientific monograph on the chemical compounds of a single metal. However, a study of Biringuccio's *Pirotechnia* shows that most of the material the *Triumph-Wagen des Antimonii* covers was well described a century before its publication. Other sources were also probably used. It is nevertheless an important work that disseminated much useful chemistry to a wide audience through its translation into Latin and other languages.

Interestingly, the *Haligraphia, das ist, Gründliche und eigendliche Beschreibung* published in 1603, a year before the *Triumph-Wagen des Antimonii* appeared, is the only work published by Thölde under his own name. It treats the salt works of Lueneburg, with a description of the surrounding village, mining operations, mineralogy, purifiying, economics (including yeilds, costs, wages), etc. It has been pointed out that this work bears a strong resemblence to the *Letztes Testement* attributed to Basil Valentini and published in 1626.[628] It was perhaps the slight reception the *Haligraphia* that caused him to publish

[626] Gmelin, *Geschichte der Chemie*, 1788, **1**, p. 586.; Partington, *History of Chemistry*, 1961, **2**, p. 276-280.

[627] Partington, *History of Chemistry*, 1961, **2**, p. 183-203.

[628] Hoefer, *Histoire de Chemie*, 1866, **1**, p. 481.

under the name of Basil Valentini.

One of the last important members of the iatrochemists whose contribution has been underestimated was Johann Rudolph Glauber [1604-1670]. As a medical man, he acquired extensive knowledge about acids and salts and their interrelationships, but was otherwise without formal training. He focused his energy on chemistry becoming a very able and practical chemist who may justifiably be called one of the first chemical engineers. Glauber improved the methods of preparing several mineral acids, and may have been the first to recognize metathesis, or double composition reactions. He followed Paracelsus' teachings to such a degree he is sometimes called "The Paracelsus of the Seventeenth Century." He bases his chemical philosophy on the three principals of salt, sulfur, and mercury, which he follows through out the wide range of his publications. Glauber's books, like those of Paracelsus and van Helmont, also contain much superstition and mysticism, but he keeps to a practical approach where chemical experimentation is concerned.

Glauber devised improved methods for the preparation of sulfuric, nitric, acetic, and hydrochloric acids. The last he called muriatic acid (meaning brine) because of the salt used in its manufacture. Prior to Glauber, hydrochloric acid was created by distilling a mixture of ferrous sulphate and salt. Instead, he used sulphuric acid and salt to prepare the acid and sodium sulphate simultaneously. Glauber was the first to describe this sulphate product, also known as "Glauber's salt", a substance that he thought was so remarkable he called it *sal mirabile* (miracle salt). By dissolving various metals in hydrochloric acid, Glauber investigated the medical properties of the resulting compounds. It was during the preparation of these chlorides that he grouped some of the fundamental truths of chemical affinity. It is clear, even though he uses mystic language to describe them, that he grasped the nature of several chemical reactions. His far ranging interests included explosives, wines, and poison gases, about which he predicts their use in chemical warfare. He discusses ideas about industrial chemistry linked to a national economy that were much advanced for their time. Glauber's writings may have influenced Otto Tachenius [c1620-1690] who developed a clear idea that salts are the end result of a chemical reaction between an acid and a base.

The iatrochemists were the pioneers in revising the ancient theories. In their writings they expressed their view of chemistry, by describing what was observed in the laboratory, and when necessary breaking with the old doctrines. For the first time they made scientific discovery through experimentation, a philosophy that would soon dominate not only chemistry but the whole of science. The results of their experiments would show that even complex compounds could be broken down to manageable components. They showed for example, that salts were the product of a chemical reaction between an acid and a base, and they began to view minerals as the results of similar reactions inside the earth. These new discoveries were slow to penetrate the fabric of daily life and the alchemical ideas of transmutation was well as believes that minerals grew like roots on some giant subterranean bush continued to dominate.

### 6.1.1 The Housecleaning[629]

**REWORK:** The iatrochemistry of the sixteenth and seventeenth centuries brought a practical foundation on which the science of chemistry could be erected, but the concepts of the old alchemy still prevailed. Before the science could flourish, a general housecleaning of the old ideas had to occur. From the mid-seventeenth to the end of the eighteenth century just such an expurgation happened. The centuries worth of accumulated chemical concepts and theories were critically reviewed and on an

[629] Further historical information may be found in: Hélène Metzger., *Les doctrines chimiques en France du début du XVIIe à la fin du XVIIIe siècle.* Nouveau tirage. Paris, Albert Blanchard, 1969. [1]-496 p. [History of chemical theories in France from the beginnings of the 17th century to the close of the 18th century.] • David R. Oldroyd., "Some phlogistic mineralogical schemes, illustrative of the evolution of the concept of "earth" in the seventeenth and eighteenth centuries," *Annals of Science*, **31** (1974), p. 269-305. • *ibid.*, "Mechanical mineralogy," *Ambix*, **21** (1974), p. 157-178. • *ibid.*, "Some neoplatonic and stoic influences on mineralogy in the sixteenth and seventeenth centuries," *Ambix*, **21** (1974), p. 128-156.

individual basis either accepted or discarded. Unfortunately, the process was painfully slow because there was a tendency to set the garbage to the side rather than toss it completely away. This meant that periodically the old concepts reappeared in a modified form, thus handicapping the sciences actual progress.

During the seventeenth century, chemistry was not the only study submerged in the ancient ideas. This led to a growing support for the experimental approach to science that was championed not by scientists but by philosophers. Francis Bacon [1561-1626] had an optimistic vision of science that he expressed in his *Novum Organum* and *New Atlantis*. He pioneered in leading science away from Aristotelian ideas to a study based upon fact collecting. In a somewhat different fashion the 1637 *Discours de la Methode* by Rene Descartes [1596-1650] introduced the principle of systematic doubt, which says accept nothing that cannot be established to be true. From this certain reality one then would deduce an outcome by dividing the problem into as many parts as possible and moving from simple to complex. This approach was successfully applied to studies in mechanics and optics.

Support for the Baconian view led to important chemical work being carried out by Robert Boyle [1627-1691], a wealthy Englishman whose enthusiasm for science stimulated the formation of the Royal Society. In 1661 Boyle published *The Sceptical Chymist* in which he set out to demolish the concept of the four elements and the three principles. He showed that there was no sound basis for regarding these substances as elemental. Boyle knew from his experiments with acids that dissolved sulfates could be precipitated by calcium salts, and solutions containing silver by the addition of hydrochloric acid. He further observed the color of ammonium copper oxide resulted from the actions of ammonium and hydrochloric acid vapors on copper, the amalgamation of gold and silver through the introduction of mercury, the reaction of iron salts to tannic acid, by which Boyle was able to detect iron in hæmatite. He was able to separate gold from copper through treatment with nitric acid, and silver from copper through precipitation with copper.[630] Boyle's works are an excellent source as regards the chemical knowledge of his time. He was one of those who laid the foundations of qualitative analysis. In his *?????* of 1672 he utilized flame colors, spot tests, fumes, precipitates, specific gravity, and solvent action as analytical tools. His work with indicators like syrup of violets led to the association of various acidic and alkaline substances. The value of these experiments did not greatly influence the contemporaries of Boyle, the theme of the period being quantitative analysis, applicable only to a particular study or use. Alchemy still governed chemistry and chemical studies of minerals remained vague and insignificant.

The principal problem that had to be faced was chemical identity. Different substances had been confused with one another since antiquity, and identical substances were known under a variety of names and considered to be different. There was no clear recognition of the fact that some substances were building blocks of which other substances were composed, or that subtle replacements could take place in chemical reactions.

In Germany, where chemistry was closely associated with mining and smelting, there arose a new theory to take the place of the ancient believes. Johann Joachim Becher [1635-1682] in his *Physicae Subterraneae* (Subterranean Physics) of 1669 concluded that all bodies were composed of three earths: *terra lapidae* (stony or vitreous earth), *terra mercurialis* (mercurial earth), and *terra pinguis* (oily earth). According to his theory, combustible bodies contained "oily earth" that was released during combustion, leaving behind only "stony or vitreous earth." When charcoal is consumed by fire, the oily earth is driven off, leaving behind only a few ashes. Charcoal must therefore be very rich in the oily earth. A calx or a metallic compound can be returned to its metallic state by heating it with charcoal because the charcoal is a rich source of oily earth, which is absorbed by the calx (oxide) to produce the metal. With his new theory as

[630] Kopp, *Geschichte der Chemie*, 1866, **2**, p. 59.

support, he zealously attacked the Aristotelean philosophy in so far as their belief that elements with a peculiar properties exist.

Furthermore, Becher's theory could explain how the different mineral species originated within the earth. In fact, he recognized that they were many mixtures that were a combination of two or more substances, and that one approach to understanding them was to separate the various substances and systematically study them. Becher believes that by knowing the components of the combinations, one learns a kind of alphabet from which the book of nature could be read. Becher advocates having on hand a collection of minerals and compounds made from them to employ as comparison material during the analysis. He was a proficient chemist, and Becher claims in one day to have made 50 such comparisons. He further says that in two years time, he had performed more than 3,000 analysis of minerals, that had cost him the small sum of 100 ducats spent on the purchase of coal, glass, etc. This was exceptional, he remarks, because others had spent many thousands without any return. It is remarkable and unfortunate that Becher's many experiments on the chemical characteristics of minerals did not led to further research.

Georg Ernst Stahl [1660-1734] was one of the leading chemists of his age. He greatly extended Becher's theory in his *Specimen Beccherianum* of 1703. In that book, Becher's ideas are developed into an elaborate chemical system in which the term "phlogiston" replaced the *terra pinguis*, thus inventing the phlogiston theory. Stahl theorized that the metals and other combustible substances were formed in a combustible earth and described that combustion by air driven away from the combustible earth. He believed the principle of combustion is in the fuel rather than in the air. When Stahl asked foundry men what function the charcoal played in reducing the calx (oxide) to its metal, he was told that the metal buried itself in the charcoal to escape the heat of the fire. To observe firsthand the action of charcoal, he heated a calx of lead in a furnace, then dropped small pieces of charcoal onto the calx. Wherever the charcoal fell on the heated mass, a small bit of lead appeared. It seemed obvious that the charcoal added some ingredient that was absorbed by the calx to create the metal. Stahl theorized therefore, metals all contained phlogiston, which explained their common properties of density, luster, and malleability. It required sometime for the theory to accepted, but by the mid-eighteenth century, it was predominant.

The potential comprehensiveness of the phlogiston theory proved amazingly good in a world in which chemistry was still held together by ancient theories. Not only did the theory explain combustion and calcination as being caused by the loss of phlogiston, it explained the smelting of ores equally well. Since the oxide of a metal is converted into metal by heating with charcoal, a substance rich in phlogiston. Stahl argued that phlogiston was transferred from the charcoal to the calx, converting the latter into the metal. Respiration, as well as many other chemical changes, were also explained in terms of phlogiston concepts.

Swedish chemists began to dominate mineralogical studies. Urban Hiaerne [1641-1724] in his *Een kort Anledning till Åtskillige Malm-och Bergarters Mineraliers Wäxters* (1694) presents the first important contribution to mineralogy, which focused the activities of other Swedish researchers to the chemical anaylsis of minerals and mineral waters. Many subsequent naturalists considered this work to be one of the key publications setting mineralogy on a chemical foundation. The monograph describes the results of various analyses on stones and mineral waters that Hjärne performed. For example, he notes that carbon dioxide evolves from some minerals after treatment with acid. Underlying the descriptions is a classification showing elements of a traditional type. The author distinguishes seven divisions: water, earths, stones, metals, semi-metals, salts and sulphurs. Other subdivisions are noted under some of these categories including common stones, precious stones, figured stones, useful stones, and stones derived from animals.

Magnus von Bromell [1679-1731] wrote a modest, little mineralogy that had a profound influence upon the subsequent development

of mineral classification, but because it was based on a chemcial approach to mienralogy, also affected that area. Designed as a handbook to help the Swedish naturalist in their mineralogical studies it is written for a threefold purpose. First, to distinguish and recognize the principal minerals, and to instruct the reader upon the proper names of rocks and ores, their nature, habit and use. Second, to describe which types of useful minerals should be found in Sweden, and third, which metals and minerals had already been found in the kingdom. This last section emphasises those minerals and ores for which additional deposits needed to be located.

In this work, Bromell uses chapters to separate the divisions of the minerals, ores and petrifications. Within each chapter the properties of the group are described. By this method, the author developed a mineral classification that employs both physical and chemical properties. He divides minerals into earths, salts, sulphur and sulphurous rocks, stones, minerals and semimetals, and ores and metals. These divisions parallel the classifications of John Woodward and Urban Hjärne. Like Agricola, Bromell subdivides the earths according to their use, into medicaments, earths used by painters and dyers, earths used for cleaning and polishing, earths used in ceramics, fertilizers, earthy ores, and fuels. However, in this early attempt at physical–chemical distinction, for the class of stones, Bromell is the first mineralogist to group together species according to the more consistant property of the minerals behavior in fire.

Through his father, Bromell became a passionate collector of minerals and fossils. He had inherited the cabinet begun by his father and had considerablly added to its numbers. While studying the collection, he became curious about the effect fire had on various specimens. Employing the crude qualitative techniques of the era, various samples of what were classified as stones by Bromell were placed in fire and the resulting reactions recorded. This lead Bromell to categorize stones into four subdivisions: fire–resistant stones, stones that calcine, stones that become harder and stones that fuse and become glass. Since a stone's chemical composition ultimately determined its reaction in the fire, and therefore the category to which it was assigned, Bromell foreshadowed the more elaborate chemical classification system to be developed later by Friedrich Axel Cronstedt. Bromell also demonstrates by his emphasis upon describing the properties of minerals his interest in an orderly description of their natural characters.

Another Swede, contemporary to Bromell was the famous naturalist Carl Linnaeus [1707-1778], who was a physician and one of the organizers an first president of the Swedish Academy of Science (1739). He developed important systematic classification of plants and animals that was based on the clear subordination of taxons: class, genus, type, species, and variation. This systematic approach that may be still found today in the scientific nomenclature of plants and animals was applied by Linné to minerals. This application of a naturalistic approach to making the study of mineralogy systematic had great influence through out the eighteenth century into the nineteenth century, but the approach really was not suited for mineral studies. Since minerals do not birth like plants and animals the idea of similar families of minerals based solely on external appearance was doomed to failure. It would require a chemical approach to direct mineral systematics along a correct path, and this only after chemical techniques and theory sufficiently developed. However, Linné's focus on studying the external forms of minerals, particularly their crystal shapes, would led to important discoveries.

The *Chymische Untersuchungen* (1746) of Johann Heinrich Pott [1692-1777] and its two supplements gave the results of a reported 30,000 experiments performed by Pott to discover the secret of making porcelain. The King of Prussia had commissioned Pott to discover the secret for making Meissen porcelain. To achieve his goal, he employed the "dry method," that consisted of heating to high temperature in a furnace all manner and mixture of substances, mostly mineral in nature. The range of reactions recorded was

a model of comprehensiveness in the chemical study of the time and showed conclusively that relative reactivity could be discovered through planned, interrelated analysis. Pott did not discover the secret to making porcelain and fell out of favor with the King. But his published results had wide relevance to manufacture, and were invaluable for the further development of theories regarding chemical affinity, especially with regard to minerals.

One of the most widely known opponents to Linné's approach to mineralogy was the head of the department of chemistry and mineralogy at Upsala University, Johan Gottschalk Wallerius [1709-1785]. His *Mineralogie, efter Mineralriket* of 1747 enjoyed wide popularity being translated from Swedish into German, French, Latin, and Russian. It is considered the first detailed textbook of mineralogy published, and it contains a systematic mineralogy based on both. Chemical composition and physical characteristics, together with concise descriptions of the minerals it describes.

Another Swedish chemist and metallurgist of the time was Axel Friedrich Cronstedt [1722-1765], who was the discoverer of the element nickle in 1754. He wrote a little mineralogical volume the advocated the use of chemical composition to develop a classification of minerals. He advocated this approach based upon the results he and other were obtaining with the use of the mouth blowpipe in chemical analysis. His book, *Försök Till Mineralogie, Eller Mineral=Rikets Upställning* of 1758 was quickly translated into German, English, French, Italian, and Russian. It is the first time mineral systematic were based strictly on a chemical basis. Cronstedt also improves the mineralogical nomenclature, and is the first to separate fossils and other geological objects from minerals. He was a keen observer, and based on chemical tests says that graphite and molybdenite are not the same minerals, as was then thought, but in fact two totally different species.

[ADD MORE ON CRONSTEDT]

Torbern Olaf Bergman [1735-1784] was another Swedish chemist who left his mark on mineralogy. Bergman was a docent of physics (1759-1761), adjunct professor of mathematics (1761-1767), and head of the departments of chemistry and minerlaogy (1767-1784) of Upsala University. He developed a chemical classification of minerals, and attempted to revise the mineralogical nomenclature. His last contribution was the theory that large crystals were being built up of smaller units all of the same shape, and that these particles gave the crystal its physical properties, such as cleavage. This idea had significant impact on the morphological description of minerals, that crystals were built up from elementary particles shaped like rhombohedrons in the case of calcite. In this work on the structure of crystals, Bergman anticipated Haüy. In chemical mineralogy his fame rests in the techniques he developed in qualitative analysis of samples using both dry analysis, notably with the blowpipe, an wet methods. He led the way in the use of the blowpipe, requiring his students to learn its use, and making modifications to the tool that improved its usefulness. Bergman also introduced a large number of reagents to be used in analysis, and stressed the importance of weighing results during the intermediate steps to determine if any material had been gained or loss. He was one of the best chemists and mineralogists of his day when he died at a rather young age.

### 6.1.2 The Chemical Revolution[631]

**REWORK:** Before 1750 chemistry could not really be regarded as an independent science.

[631] Further historical information may be found in: Archibald Clow and N.L. Clow., *The chemical revolution. A contribution to social technology*. London, The Batchworth Press, 1952. xvi, 680 p., 110 plates. • E. Grison, M. Goupil, and P. Bret, eds., *A scientific correspondence during the chemical revolution: Louis-Bernard Guyton de Morveau and Richard Kirwan, 1782-1802*. Edited by Emmanuel Grison, Michelle Goupil, and Patrice Bre. Berkeley, Office for History of Science and Technology, University of California at Berkeley, 1994. vi, 257 p., illus. • James W. Llana., "A contribution of natural history to the chemical revolution in France," *Ambix: Journal of the Society for the History of Alchemy and Chemistry*, **32** (1985), p. 71-91. [On a major impetus toward a new view of the elements derived from Swedish mineralogy and chemistry, especially the work of Axel Cronstedt and Torbern Bergman.] • David R. Oldroyd., "Mineralogy & the 'Chemical Revolution'," *Centaurus*, **19** (1975), p. 54-71. • Theodore M. Porter., "The promotion of mining and the advancement of science: The chemical revolution of mineralogy," *Annals of Science*, **38** (1981), p. 543-570.

It had always been ancillary to other fields. Alchemy its progenitor was the source for man of its recipes, apparatus and theory, but that information was purposely shielded in the unwieldy allegorical language used by the alchemists in their books. Chemistry was becoming, however, a tool of the apothecary and physician. This was reflected in the many theories, which were closely related to medical issues. Also, the local apothecary is where the chemist of the time purchased their materials.

The industrial revolution had greatly increased the demand for certain chemical materials such as mineral acids and alkalis, and the need to discovery more efficient methods of production placed tremendous pressure on practical chemistry. One of the principal stumbling points that was hindering chemistry was an inadequate theory to explain how the science actually worked. The phlogiston theory that seemed to have explained so much at the start of the eighteenth century, was by the 1770s showing its inadequacies. Clearly, some fundamental assumption in the idea of the phlogiston was not correct, and chemical science could not advance until the flaw was shown.

On to this scene appeared the Frenchman Antoine Laurent Lavoisier [1743-1794]. He had an exceptional mind that worked out theory, while at the same time he could devise practical experiments to either support or disprove his theory. However, It should be emphasized that Lavoisier discovered no new substances and devised no improved apparatus. Instead, he correctly interpreted the facts already known. When he began his chemical research, chemistry was still controled by the phlogiston theory and was essentially a collection of unorganized observations. The affinities of substances towards one another had been investigated, and acids and bases had been described fairly well, but it was hardly a science. Using the results of his contemporary chemists, in conjunction with experiments of his own design, he discovered the role of oxygen in combustion and overthrew with impeccable logic the doctrine of phlogiston. This laid the foundation of modern chemistry. It has been said Lavoisier accomplished for chemistry what Isaac Newton had done for mechanics a century earlier.

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**NEED TO ADD DATA ABOUT THE IMPACT OF THE REVOLUTION**

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### 6.1.4 Science of Chemistry

**REWORK:** Carl Wilhelm Scheele [1742-1786] as well as a pharmacist and chemist who was self taught in the chemical analysis, but managed anyway to discover the five chemical elements —, —, —, —, and —. Because of the many papers he published on organic compounds he is considered one of the founders of organic chemistry. It is his detailed and meticulous analysis of minerals that gave him lasting fame.

Louis Nicolaus Vaquelin [1763-1829] was a French pharmacist before becoming a chemist. He carried out many chemical analytical studies, and is considered one of the founders of qualitative analysis. In the School of Mines in Paris, where he was a professor, he conducted studies on many minerals, which he conducted in concert with the crystallographic studies of Haüy. In 1797 his analysis of the new mineral crocoite from Berezovsky, Russia, derived the presence of an unknown metal. By 1798 he had isolated the metal naming it chromium. In that same year he first isolated from a Siberian beryl crystal a sweet tasting element that was later named beryllium by Klaproth.

Martin Heinrich Klaproth [1743-1817] was the first professor of chemistry at the University of Belin and the best chemist of his time. He stressed the importance of repeatable results i hi chemical analysis as well as full documentation of the qualitative methods used in the procedure. His careful precision led him in his analysis of various minerals to discover the new elements: zirconium (1789), titanium (1795, and independently of Gregor), tellurium (1798), chromium (1798, independently of Vaquelin), uranium (1789), and cerium (1803, independently of Berzelius).

[MAYBE SHOULD BE TABLE?]

He published his mineral analysis in various German journals and periodically

collected them into volumes in his important ————————- (6 vols., 1795-1815). He also authored his *Chemical Dictionary* (5 vols., 1807-1809).

Johann Gottlieb Gahn [1745-1818] was a Swedish chemist and friend of Scheele. He operated a mine in the Faluna Region and by his expert use of the mouth blowpipe he was able to chemically analysis its minerals. From pyrolusite he was perhaps the first to produce metallic balls. These he sent to Scheele who further purified the metal and confirmed the discovery of the new element manganese. Together with Scheele, Gahn participated in obtaining phosphorus from the ashes of horns and the bones of animals.

Hans Gadolin [1760-1852] a professor of chemistry at Åbo, Finland isolated from the black mineral yttrbite in 1787 an unknown earth.

[ADD MORE ON GADOLIN]

At the end of the eighteenth century there was an explosion of developments in chemistry connected with the work of Antoine Lavoisier [1743-1794]. He was the first to create a scientific explanation of combustion and show conclusively that no material is lost or gained during the oxidation process. This reversed ideas about the phlogiston theory, and in fact destroyed the theory.

[SEE PARTINGTON, p. 122]

### 6.1.5 Nineteenth Century[632]

**REWORK:** The development of mineralogy in the nineteenth century continued in lock step with the progress of chemistry, with the basic concepts and methods being common to both sciences. The study of crystallography helped create a method for mineral determination, as well as connecting information about chemical composition with the characteristics of the crystal shape and different physical properties.

Early in the century, a dispute arose between Berthollet and Proust concerning the constancy of the composition of chemical substances that would have important repercussions in mineralogy. The dispute that erupted in 1801 developed from analytical chemists and the ratio of specific chemical elements (base and acid) with in the salts they analysed.

Claude Louis Berthollet [1748-1822] revealed in his publications that he thought chemical composition was variable, and that the effect of temperature on the density of a body would cause the attractive force of the chemical elements to change, thereby making the chemical composition variable. Berthollet supported this view about variable composition in chemical compounds in his —— (1801) and ——- (1803) that found many chemists writing in support of his view or warring against it.

The charge against Berthollet was led by the French chemist, Joseph Louis Proust [1754-1826], who preformed numerous chemical analyses on specimens from his own excellent mineral collection. In particular, Proust studied the properties of silver minerals. He believed that Berthollet did not perform his analysis on pure samples, but on crystals that were composed of different layers that caused the chemical composition to vary. Through his excellent chemical analysis, Proust conclusively showed by 1808 that all chemical compounds were always mixed in the same proportions.

The chemical controversy between Proust and Berthollet reflected a deeper schism in early nineteenth century science. Scientists were finally freeing themselves from the heritage and old traditions, in this case alchemy. The theorists that defended either the iatrochemistry of the phologiston were by and large being replaced by the experimentalists who developed theory from what was seen in the laboratory. For the first time in the development of chemistry, the science grew through experimental advancements, which led to bright prospects for further development.

A significant role in chemistry was played by the Italians Luigi Galvani [1737-1798] and Anasasio Volta [1745-1827] with their experiments in electricity. They generated their electrical current by placing a conducting

[632] Further historical information may be found in: J. Lafaille., "Contribution de la naissance de la Chimie minérale au développement de la Minéralogie ed de la Pétrographie à la fin du XVIIIè siècle," *Travaux du Comité français d'Histoire de la Géologie*, First Series, 1978, no. 14, 4 p. • E.M. Melhado., *Jacob Berzelius. The emergence of his chemical system*. Madison, University of Wisconsin Press, 1981. 357 p.

fluid between two different metals. This Galvanic pile or battery was another tool available to the chemist that led to many new discoveries, including the decomposition of water, electrolysis of some metals, and the discovery of new elements like sodium.

Chemical developments continued to be linked to the study of minerals in the work of the Swedish chemist and mineralogist, Johan Jakob Berzelius [1779-1848]. He was the president of the Swedish Academy of Science, and one of the greatest scientists of his age. His greatest contribution was his development of an atomic theory and the correct determination of the atomic masses of most of the chemical elements known at the time (36 of the known 49). He applied his atomic theory to the devolvement of another chemical theory that linked chemistry and electricity, which he called 'electro-affinity'. Berzelius developed a nomenclature of chemical elements, and a method of writing the chemical formulas of compound substances and reactions between them.

With his determination of atomic masses of chemical elements, Berzelius had the fundamental component to correctly determine the formula of many substances, including the minerals the he experimented with. To develop his theory, he preformed over 2,000 analyses of substances that contained the 43 known chemical elements. This allowed him to publish in 1814 the first compilation listing the atomic masses, which was revised with corrected values when his table was published in 1826. From his experimental data he was able to establish a theoretical framework for various oxides and say that oxide compounds are of the form: $X_2O$, $X_2O_3$, $X_2$, $X_2O_5$, and $X_2O_7$.

Berzelius viewed all chemical compounds as having both positive and negative charged components, and that the substance was held together by the mutual attraction of these oppositely charged elements. These electropositive and electronegative parts corresponded to the base and acid, respectively, of the substance. His theory made it possible to explain the integration of substances with each other, their behavior in solution, an the reason for the formation of chemical compounds in strict proportions. To facilitate the communication of his ideas, Berzelius proposed in 1813 to designate the element by the first two letters of the Latin name of the element, and dropping the old alchemical symbols completely. He also championed the writing of chemical formulas, to consist of the electropositive (base) portion followed by the electronegative (acid) part. A practice followed to this day.

In his work, Berzelius investigated the chemical composition of many minerals. To expedite his investigations, he made liberal use of the blowpipe, which he had been taught by J.G. Gahn, but which nevertheless was improved by Berzelius. Using this useful tool he discovered several elements, and was able to isolate —— in an elemental form for the first time.

Berzelius was a prolific writer, announcing his theories, discoveries, and innovations through his numerous scientific papers and textbooks. Due to the nature of his research, many of these works deal directly with the chemical composition of minerals. After being sent a large gift of minerals by Andreas Ekeberg, Berzelius analysised them, and established the large role a flint like material played in their composition. He proposed the general name "silicates" to define this type of mineral formation. Not satisfied with the classification of mineral species by their physical forms as was then the prevailing method, he developed his own classification system based on chemistry. In particular, he divided the silicates into groups depending on the relationship of metals to the silicate component ($Si_xO_y$), where x is in the ratio to y as 1:1, 1:2, or 1:3.

Although Berzelius was the most significant chemist and mineralogist of the early nineteenth century, others noticeably contributed to the chemical analysis of minerals, and in the process discovered new chemical elements.

Carl Gustav Mozander [1797-1858] was another Swedish chemist and mineralogist who investigated and discovered several rare earth elements. In 1839, he showed that the cerium earth analysised previously by Klaproth and Berzelius actually contained several similar elements, one of which he named lanthanum.

In the same year he obtained a pure cerium oxide, but metallic cerium (Ce) was only obtained in 1875 by the American chemist U.F. Hillebrand. Mozander also isolated the ———— earth, whose heterogenous nature was proven spectroscopically by Bauner, and which Auer von Welsbach in 1885 finally reduced to the elements praseodymium (??) and neodymium (??). Mozander's interest and success in studying the rare earth series encouraged others to investigate their ores and thus were discovered:

[ADD TABLE HERE.]

Reference...[633]

## 6.2 Mineral Analysis & Analysts[634]

**REWORK:** The beginnings of mineral analysis are lost in the fog of history. Assyrian, Babylonian, Sumarian, Egyptian and Biblical records show that a form of fire assay for gold and silver dating back to before 2500 B.C.E. was generally known, and it can be supposed that metallurgists evaluated any new ore by assaying a sample. The fire assay of gold and silver probably came close to modern standards of accuracy by 600 years ago if not earlier, and other methods of assaying for other metallic ores have been developed since then. Assaying is an early qualitative approach to the problem of chemical composition. It tells if a specific metal is present it does not say if there are other elements present. In the eighteenth century chemistry developed new techniques of analysis that allowed for the quantities of every element contained in a substance to be determined with accuracy. This had a profound impact in mineralogical science.

The task of the analyst is to choose a line of attack for the material on hand, to modify existing analytical methods, or if necessary invent new ones to carry the chemical analysis to completion, and properly interrupt the results. In the beginning, even the procedures had to be invented, before the chemists could show their true skill. Between 1757 and 1781 Andreas Sigismund Marggraf [1709-1782] made many advances of analytical significance, including distinguishing between soda and potash, the use of ferrocyanide as a reagent for iron, the use of the blowpipe and the microscope as an aid in the identification of salts.[635] Many of his papers were collected together in the *Chymischer Schriften* (2 vols., Berlin, 1761-7), which was also translated into French by Formey. He was skilled at chemical analysis, and studied phosphorus, silver, zinc, barite, potash, gypsum, etc. Before his time, qualitative chemical analysis of minerals was hardly ever attempted, and in fact, although Marggraf analyzed many mineral compounds, he appears never to have published a complete analysis of a mineral.

Among the first scientific publications of Antoine Laurent Lavoisier [1743-1794] were his chemical analysis of gypsum, submitted to the Paris Académie des Sciences in 1765 but published in 1768.[636] In his analysis Lavoisier correctly determines that gypsum ($CaSO_4$) is a combination of vitriolic acid with a calcareous earth and that it has the same composition as selenite. He showed that plaster, which is made from the dust

[633] S.J.St. Beckmann., "Mineralogische Beschriebung und chemische Untersuchung eines grünen, äusserlich dem Chrysopras ähnlichen Fossils aus dem Zillerthal in Tyrol.," *Neue Journale der Pharmacie [Trommsdorff]*, **20** (1830), 31-7.

[634] Further historical information may be found in: Frank Greenaway., "The early developement of analytic chemistry," *Endeavour*, **21** (1962), p. 91-97. • Max H. Hey., "Mineral analysis and analysts," *Mineralogical Magazine*, **39** (1973), p. 4-24. • Herbert A. Laitinen and Galen W. Ewing, eds., *A history of analytical chemistry*. Washington, Division of Analytical Chemistry of the American Chemical Society, 1977. xiv, 358 p., illus. • David R. Oldroyd., "Some eighteenth century methods for the chemical analysis of minerals," *Journal of Chemical Education*, **50** (1973), p. 337-340. • *ibid.*, "A note on the staus of A.F. Cronstedt's simple earths and his analytical methods," *Isis*, **65** (1974), p. 506-512. • James R. Partington., *A history of chemistry*. London, Macmillian, 1961-70. Vol. 1, pt. 1, 2-4. xlv, 370 p.; xxiv, 795 p.; xxiii, 854 p.; xxxi, 1007 p. [No more published. Indispensable standard reference in the history of chemistry.] • G. Rath., "Die Mineralquellenanalyse im 17. Jahrhundert," *Sudhoffs Archiv*, **41** (1957), p. 1-9. • Eberhard Schmauderer., "Künstliches Ultramarin im Spiegel von Preisaufgaben und der Entwicklung der Mineralanalyse im 19 Jahrhundert," *Technik Geschichte*, **36** (1969), p. 314-333. • Ferenc Szabadváry., *History of analytical chemistry*. Translated by Gyula Svehla. Oxford, London, etc., Pergamon Press, 1966. ix, [1], 418 p., illus., notes, indexes.

[635] Partington, *History of Chemistry*, 1961, **2**, p. 723-729.

[636] Antoine L. Lavoisier., "Analyse du gypse," *Mémoires de l'Académie Royale des Sciences, Paris*, **5** (1768), p. 341-357.; Partington, *History of Chemistry*, 1962, **3**, p. 378-379.

of gypsum, hardened due to its combination with water. He also provides full geological data concerning where the material is found. The scholarship displayed in this paper brought Lavoisier to the attention of Guettard, who invited him to assist in the preparation of the *Atlas et Description Minéralogiques de la France* (1780), which mapped the mineralogical wealth of France. Interestingly, in a second memoir on gypsum that Lavoiser delivered to the Académie in 1766, but which was only first published in 1865, he shows that gypsum can be artificially formed in the laboratory from the reaction of chalk and sulfuric acid.[637]

By the middle of the eighteenth century, then, there was a large accumulation of data about qualitative analysis that could be drawn upon to form a general scheme for mineral analysis. However, the trick to a good analysis was to place the entire sample into a solution, which it was discovered could be achieved by fusion with an alkali. This technique had been known since the earliest glass makers colored their products, but it was not an obvious step. Once discovered, however, these procedures collectively became known as the wet method of analysis. Because the chemical precipitates at the various stages could be weighed on a balance, it was also called gravimeteric analsis.

The first chemist-mineralogist to use these procedures in his chemistry was the Swedish Torbern Olaf Bergman [1735-1784].[638] A brillant man, who had persistant ill-health, Bergman prepared in a period of less than two decades a chemical analysis of seemingly every substance that came into his posession, including many minerals . Among the large collection of papers and dissertations published by Bergman and his students are essays on: ankerite,[639] tin sulphide (1781),[640] stibnite (antimony sulfide, 1782),[641] volcanic products (1777), in which he gives an analysis of basalt (silica 52, alumina 15, calcium carbonate 8, iron 25),[642] lithomarge (1782),[643] asbestos (1782),[644] the hydrophane (*oculus mundi*) (1777),[645] tourmaline (1779),[646] cassiterite (tin) from Siberia (1781),[647] observations on minerals (1784),[648] mineral waters of Medevi (1782),[649] the precipitation of cobalt, nickel, platinum, and manganese (1780),[650] magnesia nitrate (1777),[651] and with little success, complete analyses of emerald, ruby, sapphire, topaz, and hyacinth (probably idocrase).[652]

Bergman is also the first to issue a manual that explained the steps in analysing a mineral in a general way, *Dissertatio Metallurgica de Minerarum Docimasia Humida* (1780). It is an important disseration responded to by Petrus Castorin, which is a greatly expanded and revised edition of Bergman's earlier paper, "Chemisk Afhandling om Järnmalmus Proberande" (1777). The text gives detailed and practical methods for qualitative and quantitative analysis of 15 different metals found in ores, including silver, mercury, lead, iron, copper and zinc. The wet method of analysis is preferred, he says, because of its accuracy even though it takes considerably longer to perform than the dry assay method.

Sadly, the published analyses of Bergman are not as accurate as they could have been. There were several reasons for this. He tended not to consider the contribution of some of the less common "earths" in the analysis. Sometimes, he would include the less accurate results of his students in his own work, and finally, the mortar he used to crush particularly hard samples would contaminate

[637] Antoine L. Lavoisier., "Sur le gypse," *Mémoires de l'Académie Royale des Sciences, Paris*, 3rd Serie, **8** (1865), p. 128-136.; Partington, *History of Chemistry*, 1962, **3**, p. 379.

[638] Partington, *History of Chemistry*, 1962, **3**, p. 179-199.

[639] X; A, ii, 184.

[640] XLI; A, iii, 157.

[641] XLII; A, iii, 164.

[642] XVIII; A, iii, 184-290.

[643] XLIV; B, iv, 142.

[644] XLV; B, iv, 160.

[645] XX; KAH, 1777, xxxviii, 347; A, 11, 54.

[646] XXXI; KAH, 1779, xl, 224; A, ii, 118.

[647] KAH, 1781,ii,328.

[648] XLIX; KAH, 1784, v, 109; B, v, 98.

[649] 15 XLVI; KAH, 1782, iii, 288; B, iv, 346.

[650] XXXVI; KAH, 1780, i, 282; B, iv, 371.

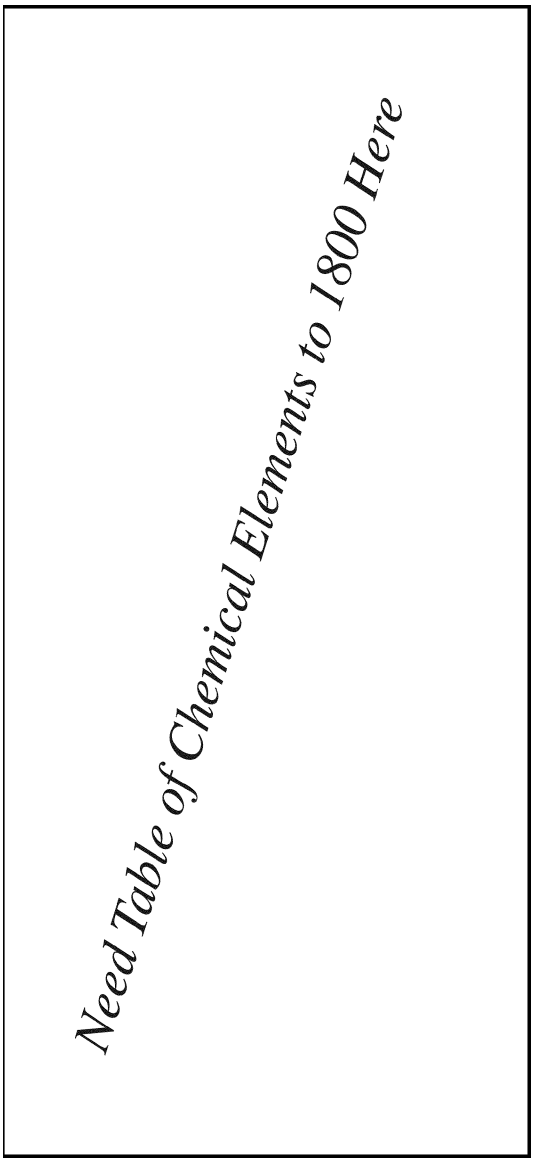
[651] XXIV; KAH, 1777, xxxviii, 213; B, v, 111.

[652] XXI.; A, ii, 85.

the test sample with silca, which tricked Bergman into believing the original substance contained the element. His authority was considerable, and his analytical work was not questioned until better chemcial techniques were developed, which happened shortly after his death. Nevertheless, Bergman and his pioneering procedures of the "analysis in the humid way" was of fundamental significance.

After Bergman, progress in mineral analysis was rapid. Others soon began to investigate minerals and precious stones chemically, and they began publishing papers and books that described their findings: Achard,[653] Bindheim,[654] Forster,[655] Gerhard,[656] Scheele,[657] Withering,[658] among them. In Ireland, Richard Kirwan [1733-1812] used "humid" techniques in his mineral analyses. By 1784 he was able to tabulate 74 analyses of rocks and minerals completed by himself and others in the first edition of his *Elements of Mineralogy*. He also includes in the book a useful description of his analytical procedures.

By 1800, 32 elements were recognized, many of these having been discovered through analysis of minerals. The greatest strides in this direction were made in Germany by Martin Heinrich Klaproth [1743-1817], the greatest practical chemist of his age. He did not make sweeping theories about his science, but instead his work reformed chemcial analysis techniques. He published many papers on the chemistry of minerals that included detailed descriptions of his laboratory methods, which show his careful and accurate techniques. Periodically, these papers were collected together and published as a volume of the important, *Beiträge zur chemischen Kenntniss der Mineralkörper*, of which six volumes appeared between 1795 and 1815.




Chemical Elements Known In 1800

Klaproth extended mineral analysis in a number of new directions. Whereas earlier chemists habitually recalculated their result to always total 100 percent, Klaproth insisted that his results be accurately reported, even if they did not total exactly 100 percent. He includes information on the weights of his samples and reagents, and was at pains to

[653] Franz Carl Achard., *Bestimmung der Bestandtheile einiger Edelsteine*. Berlin, 1779. 128 p., 2 plates.; *ibid.*, "Chemische Untersuchungen der Edelsteine" *Abhandlungen des München Akademie*, 1800, p. 219-350.

[654] Johann Jacob Bindheim., "???". See Weeks 7th edition.

[655] Johann Reinhold Forster., *An Easy Method of Assaying and Classing Mineral Substances*. London, 1772. 44 p.

[656] Carl Abraham Gerhard., *Beiträge zur Chymie und Geschichte des Mineralreichs*. Berlin, 1773. 2 vols.

[657] Carl Wilhelm Scheele., "???".

[658] William Withering., *Outlines of Mineralogy*. London, 1783, being an English translation of T.O. Bergman's *Sciagraphia*.

remove any potential source for error. Purity of his chemical reagents is emphasised, and in this era when the chemist had to make his own, Klaproth describes processes for purifying them. He also chose his apparatus carefully, so that unwanted contaminants were not introduced to the test sample. He introduced the use of agate, flint, and diamond mortars, correcting for weight losses in the mortar and crucible. He initiated the technique of drying precipitates to constant weight, and if ignition created a stable residue without alteration, this technique was used. Before Klaproth, Bergman had suggested the idea of precipitating metals, i.e., silver as the chloride, calcium as the sulfate, and lead as the sulfide. This idea was expanded by him to incorporate other metals.

Showing his tremendous skill during his mineral analyses, Klaproth frequently found samples for which the analytical procedures failed to total close to 100 percent. This suggested the presence of some additional element contained in the mineral that had not previously been recognized. Leads such as this were persued by Klaproth, which led to him either discovering or confirming a recent discovery of the elements: zirconium, uranium, tellurium, and titanium. For example, in his 1789 analysis of zircon from Ceylon he discovered an earth (oxide) that made up 70 percent of the composition of the sample. Bergman had previously thought this material was a combintation of aluminum, calcium and iron oxides; however, Klaproth recognized it as actually the oxide of a new metal, which he named zirconium, which was only first isolated in elemental form by Berzelius in 1824.

In France, Nicolas Vauquelin [1763-1829] used "humid" techniques in his mineral analyses. Haüy at the École des Mines supplied him with samples of minerals for analysis. Generally, these analyses were inferior to Klaproth's because Vauquelin paid less attention to impurities in reagents and to the purity of his samples. Nevertheless, he did produce good results. Analysing crocoite from Siberia, he isolated a new metal that because of the vibrant colored compounds it formed was given at the suggestion of Haüy and Fourcroy the name chromium. In the decompostion of beryl crystal given him by Citizen Patrin, he was the first to recognize the oxide of beryllium, an element not isolated until 1828 by F. Wöhler.

By the late eighteenth century, qualititative mineral analysis had become recognized as an important branch of mineralogical chemistry and many books on the subject soon began to appear. Carl Friedrich August Hochheimer authored the 2 volume *Chemische Mineralogie, oder vollständige Geschichte der analysischen Untersuchung der Fossilien* (1792-3), in which he covers the development of mineral analysis, together with reviews of the various techniques so far established. In 1801, Lampadius published what is generally considered the first textbook on mineral analysis with the *Handbuch zur chemischen Analyse der Mineralkörper* (Handbook to the Chemical Analysis of Mineral Bodies). The *Practical Essay on the Analysis of Minerals* of 1804 was prepared for the English readership by Friedrich Accum to describe the apparatus, preparation, purification, and testing of reagents, and giving procedures for the analysis of a considerable number of minerals. Furthermore, Accum taught classes in chemistry to an eagar public at the Royal Institute(?). The techniques available were still being perfected, and the insturments, in particular the balances, were still not accurate enough. Klaproth used, for example, a balance that appears to have been accurate to one grain (about 30 mg) so that although he usually used 5 to 10 grammes of a mineral for analysis, his best results could only be accurate to one percent, which he clearly recognized. Many later workers were less cautious.

In England, William Hyde Wollaston [1766-1828] an enthusiastic and talented investigator in various fields of chemistry and physics investigated the new platinum metal being imported from South America since about 1750. It aroused the attention of chemists because of its chemical inertness, and the extremely high temperatures needed to melt it—virtually beyound the furnace technology of Wollaston's time. He instead found a method to prepare a platinum mass by the thermal decomposition of ammonium

chlorplatinate. The process kept secret until his death brought him a steady income. However, during his studies of native platinum, he discovered the two metals palladium and rhodium in 1803. Together with osmium and iridium, discovered by Smithson Tennant [1761-1815] in 1804, they form the platinum group of metals.

With the work of Swedish Jons Jakob Berzelius [1779-1848] the modern period of gravimetric analysis is entered. Though many improvements were still to come, and a large number of chemical separations still gave trouble, Berzelius the best chemist of his age. In his mineral analyses he devised many new procedures and introduced new reagents such as hydrofluoric acid for the decomposition of silicates and the determination of silica. He also greatly improved the technique of analysis by introducing the use of a filter paper that when burned left little ash behind and the cleaning of precipitates by the use of a convenient wash bottle. His technical improvements were so great that he was the first researcher to determine the elemental atomic weights with accuracy—a study he used in part to base his system of mineral classification (see §9.——).

In 1821, Friedrich Stromeyer [1776-1835] published his *Untersuchngen über die Mischung der Mineralkorper*, which was the first in a proposed series of volumes describing the chemical makeup of minerals. In the forward, he writes that it was the influence of Berzelius' researches that motivated him to prepare this book. It is a collection of investigations into the analyses of minerals that he has made with the best technique of the time. Thirty species are treated including aragonite, aluminite, magnesite, strontianite, boracite, apophyllite and spodumene. In several cases Stromeyer presents analyses from multiple localities to show that the composition of a mineral species does not vary much deposit to deposit. Unfortunately, no more volumes were published, although Stromeyer continued publishing papers dealing with the chemical analysis of minerals.[659]

By the first decades of the nineteenth century, as is shown by the 1829 first edition of the *Handbuch der analytischen Chemie* of Heinrich Rose [1795-1864], a set of workable methods for the separation and determination of each of the known elements was available. The techniques and instruments used in wet gravimeteric analysis had advanced to a point where the priority shifted from manipulation of the samples to discovering new procedures and chemical reagents that would give results of greater accuracy. The remainder of that century saw hundreds of new procedures devised, many of which arose out of the discovery of new minerals, elements, and compounds. Still others came from the application of chemistry to problems in industry, agriculture, and medicine.

Among the many important new procedures were, for example, the molybdate method for phosphorus, introduced by Franz Leopold Sonnenschein [1819-1879],[660] and the method for the determination of alkalies in silicate minerals and rocks, devised by J. Lawrence Smith [1818-1883].[661] Elaborate schemes were also devised for the analysis of complex materials, a notable example being that of William Francis Hillebrand [1853-1925] for the complete analysis of silicate and carbonate rocks.[662]

The chemist Karl Remigius Fresenius [1818-1897] is generally recognized as the leader in the development of chemical analysis in general and gravimetric analysis during the second half of the nineteenth century. He opened in 1848 a laboratory that became a center for training analytical chemists, for research on methods of analysis, and for commercial analytical work done for individuals, government bodies, and industry. Students there used his textbook, *Anleitung zur qualitativen chemischen Analyse* first published in 1846, that contains instructive procedures for the qualitatitive analysis of all

[659] A complete list of Stromeyer's papers can be found in the *Royal Society Catalogue of Scientific Papers*, **??**, p. ??-??.

[660] F.L. Sonnenschein., "???," *Journ. prakt. Chem. (Erdmann)*, **53** (1851), p. 339.

[661] J.L. Smith., "???," *American Journal of Science*, series 2, **15** (1853), p. 234; **16** (1854), p. 53.

[662] W.F. Hillebrand., "???," *Journal of the American Chemical Society*, **16** (1894), p. 90.

the known elements. Because pure reagents were not commercially available at the time, detailed directions for their preparation are also included.[663] The book was immediately recognized as a work of superior merit. Six editions were published until 1898, the year after Frensenius' death, together with translations into Chinese, Danish, Dutch, English, French, Polish, Russian, and Spanish. It became (and still is) the best textbook on chemical analysis written.[664] Much information on the chemistry of minerals is contained within its pages, with the first part devoted to qualitative analysis of minerals.

Together with the newly devised procedures, new inventions stimulated analysis. Until the mid nineteenth century, charcoal was often used as the fuel for furnaces and ovens and alcohol for laboratory burners. In 1855 Robert Wilhelm Bunsen [1811-1899] invented the convenient and clean gas burner that still bears his name. In 1878, Frank Austin Gooch [1852-1929] invented the glazed porcelain filter crucible that is used in high temperature analysis.

## 6.3 Chemical Compostion of Minerals

**REWORK:** Lavoisier's new theory of chemistry was gradually accepted, and by the end of the 18th century even England and Germany, where any ideas originating from revolutionary France were treated with grave distrust, had accepted the new theory. But at this time the laws governing stoichiometry, despite the valuable work of Richter, Proust and Dalton were not conclusive enough to be used for exact calculations. Dalton's atomic theory, and also the laws of stoichiometry, only became an integral part of quantitative analysis after accurate values of the atomic weights had been established. This work was carried out by Berzelius at the beginning of the 19th century, and his invaluable work marks the start of a new period in chemical history.

Berzelius's work was furthered in that he was able to rely on a large amount of analytical information, which had not been available to Wenzel or Richter. This was largely due to the rapid development of mineralogy between the years 1790-1810. During this time the quantitative composition of a large number of minerals and naturally occurring salts was established with a fair degree of accuracy. Mineral analysis was the primary concern of chemists throughout Europe at this time, but three names stand out above the others. Kirwan, Klaproth and Vauquelin, although only slightly more illustrious than most of their contemporaries, give a good impression of the manner in which analysis was carried out in Europe at that time.

Richard Kirwan was born in Ireland in 1735, where he first studied and practiced law. However, being a rich man he soon retired and lived in London and Dublin, and at his country estate, where he engaged himself in the study of science as a hobby. His main interest was in analysis. He was a member of the Royal Society, and for a long time he supported the phlogiston theory in opposition to Lavoisier, but eventually realized that it was untenable. He died in Dublin in 1812.

Kirwan describes many types of salts, and the results of his analyses were extremely accurate, a fact which assisted both Richter and Berzelius in their investigations on stoichiometry. However, there was little in his work which was new, the main object being to make Bergman's methods of water analysis quicker and more simple. His work was published in London in 1799, under the title An Essay on the Analysis of Mineral Waters.

Kirwan's book is outstanding, mainly because of its comprehensive list of references, which summarize all the work carried out in the field of water analysis since the time of Bergman. The first part of the book describes the various compounds which can be found in water. Some of his observations in this section are remarkable. For example, he noted that:

Aerated lime is itself soluble in an excess of fixed air (C02), as Mr. Cavendish

[663] The first reagents of guaranteed purity were placed on sale by the Kahlbaum Co. in Germany in 1880.

[664] Karl Remigius Fresenius., *Quantitative chemical analysis, by the late Dr. C. Remigius Fresenius ...* Authorized translation of the greatly amplified and revised 6th German edition, by Alfred I. Cohn. New York, J. Wiley & Sons, 1904. 2 vols. [The great quantitative chemistry textbook, translated into English.]

first discovered, and here two questions arise important to subsequent calculations, namely what quantity of aerated lime can be held in solution by a given volume of water fully aerated ... (p. 17).

He also compared the available information concerning this problem, but did not arrive at a definite conclusion.

In the second part of his book he describes the various tests that can he applied to identify the various compounds. There is little or no reference to any new reactions, the only difference being that the book is classified according to the different compounds, and alongside each is given the test for its identification. Carbon monoxide, which was discovered by Priestley, is also referred to in the section on gases; Heavy inflammable air or carbonated hydrogen. This air is distinguished by the fact that it burns without explosion when mixed with common air. It is not absorbed by limewater, but water over which it is burned precipitates lime-water, as fixed air is produced.

As can be seen, Kirwan had discontinued the use of the phlogiston nomenclature. One of the reagents that he used was boric acid, and he observed that it gave a precipitate with lead nitrate, but that carbonates and sulphates must first be removed (p.84).

Kirwan also carried out interference studies (p. 136) and records the salts which cannot be present for a given salt being determined, although he mentions the fact that in some cases small quantities of the interfering salt do not have much effect. As examples of salts which cannot be determined in the presence of each other, he gives the alkali carbonates and metal salts, the alkali sulfates and the alkaline earth salts, magnesium sulphate and calcium nitrate or chloride, and magnesium nitrate and calcium nitrate or sodium nitrate (?). The reasons for some of these salt pairs being classified as interfering is not very clear.

Kirwan suggests a simple procedure for the determination of the total salt content of water without the need for a quantitative examination

There is a method of calculating the quantity of salt in 1000 parts of a saline solution

whose specific gravity is known, which, however inaccurate, is yet useful in many cases as the error does not exceed 1 or 2 per cent, and sometimes is less than 1 per cent. It consists

simply in subtracting 1000 from the given specific gravity expressed in whole numbers, and multiplying the product by 1.4. It gives the weight of the salts in their most desiccated

state and consequently freed from their water of crystallization. The weight of fixed air (C02) must also be included, thus for a solution of common salt having its specific gravity

1.079, I find the difference from 1000 is ... 79 and 79 x 1.4 = 110.6, then 100 gr of such solution contain 110.6 gr of common salt ... (p. 145).

He also mentions the error involved in the analysis carried out with "tests" which had becn mentioned by other authors, that it does not give any indication which acid reacts with which base to form the salt. He concludes by saying that

The usual method of applying tests is similar to that of sending out adventurers to an unknown country to see what discoveries they can make, hence that indications are vague and unconnected. Whereas if they were limited to some particular object, and so combined and arranged to prove or disprove its existence, their indications might be rendered certain and precise; and such information I have already shown them capable of conveying, when employed with single and definite views (p. 162).

He elaborates this view later in his book.

After this Kirwan deals with the practical aspects of analysis, and differences between qualitative and the quantitative examinations The Analysis of a Mineral Water embraces, as I have already noticed, two objects: the discovery of the different species of ingredients contained in it, and the determination of the weight of each. How the species are discovered I have already set forth in the chapter of Tests. The quantities of solid ingredients I determine in most instances by estimation, as being the least laborious, in many cases equally and in many the most exact (p. 175).

Kirwan attempted to resolve the problem

that he had previously stated: the problem of finding out which acid, and which base has reacted to form a salt.

He attempts by using different reagents to determine the nature of the salt, as well as its concentration, but his method is rather unreliable and complicated. It is scarcely of practical importance, although Thomson discusses it a quarter of a century later in his work System of Chemistry [1]. Kirwan supposed that the single sulphates can be separated from one another with the help of calcium, barium and strontium salts, for example, magnesium sulfate precipitates with a strontium salt, while potassium sulfate does not.

Kirwan's analytical work was famous in his time, and his results were cited all over Europe. However, at the turn of the 18th century another great chemist, Klaproth played an even greater part than Kirwan. There are very few books published during this period which do not refer to some aspect of Klaproth's work.

Martin Heinrich Klaproth (1743- 1817) was the son of a provincial tailor; after leaving the grammar school for some unknown reason at the age of 15 he became, like so many great chemists before him, an apprentice pharmacist. He first worked at an apothecary's shop in Quedlinburg, but later became an assistant in Hanover, Berlin and Danzig. In 1771 he went to work at the pharmacy of Valentin Rose in Berlin. Rose at this time was a famous chemist, but died only four weeks after Klaproth had joined him. He entrusted the education of his children and the direction of his pharmacy to Klaproth, who faithfully carried out his last wish. He was in charge of the pharmacy for ten years, until Rose's son had grown up. In 1780 he married a niece of Marggraf, and used the not inconsiderable dowry to purchase his own laboratory. Previously he had only carried out his research in addition to his pharmacy, but he now gave up pharmacy and devoted himself entirely to research. Nearly all of his work was devoted to mineral analysis. In 1788 he was elected a member of the Berlin Academy of Sciences, and in 1800 he was appointed leader of the chemical laboratory of the Academy in succession to Achard. In addition he was a Professor at the Artillery Officer Academy. In 1809 King Friedrich Wilhelm founded the new University of Berlin, and Klaproth was called to be the first Professor of Chemistry there. According to the time-table of the university he lectured on "Practical chemistry" for four hours a week for the first term, in the second term, also for four hours a week, he lectured on the subject "Introduction to chemical analysis" [2]. In his later years he had many domestic troubles and was subject to fits of apoplexy. He was ill for a long time, and had to give up his lecturing. He died on New Year's Day 1817.

Klaproth lived in the same period as the great phlogiston chemists, and like many of them he was self-taught and did not attend a university. His scientific career did not really start, however, until he was about 40 years of age, and by this time Lavoisier had expounded the new chimie francaise so that Klaproth was not bound to the phlogiston theory. After confirming several of Lavoisier's experiments, he became an exponent of the antiphiogiston theory, and was the first important German chemist openly to accept the views of Lavoisier.

Klaproth was essentially a practical scientist; he had complete faith in his experiments, and mere suppositions did not interest him. He lived at a time when violent debates were going on in chemical society concerning the various chemical views. Klaproth never took part in these, and never gave any indication of his own opinions. Klaproth examined a wide variety of minerals with great thoroughness and published his results, but here his interest ended. The accuracy of his analysis, however, was an important factor in the establishment by Proust of his law of constant proportions.

Klaproth's point of view is best characterized by his de bate with Ruprecht. Antal Ruprecht, who was Professor at the Selmecbanya Mining Academy, found that he could obtain metals from the earths (alkaline earth oxides) by reduction with carbon. This an nouncement aroused great interest in the world of chemistry and produced a bitter contro versy because hitherto earths had been considered to be elemental substances which

could not be decomposed further. Klaproth carefully repeated Ruprecht's experiments, and proved that the metals formed did not originate from the earths but from the contamination of the chemicals, and concluded that the simple earths do not contain metals. Although Ruprecht's experiments were incorrect, the idea behind them proved to be right [3]. This was confirmed a few years later by Davy, when he succeeded in reducing the earths to the metals with the help of an electric current. Klaproth did not believe this. This was an often repeated and unfortunate occurrence in the history of the sciences, of the older scientist who is ingrained with the old concepts and refuses to accept the new developments. This was the fate of the phlogiston chemists, who had spent their lives creating a theory and were quite naturally reluctant to abandon it even in the face of irrefutable evidence.

A very clear appraisal of Klaproth's contribution to chemistry is the following

He was an incorruptibly accurate researcher, but was lacking only in ingenuity or intuitive thought; had he possessed this also then he would have taken his place among the greatest chemists [4].

He discovered three new elements, uranium, zirconium and cerium, and although titanium, strontium and tellurium had previously been observed by other workers, he examined these discoveries in more detail, and also gave a name to these elements. His contemporaries credit him with the discovery of tellurium although in fact this had already been discovered in 1782 by the Hungarian, Ferenc Müller [5], in the gold-ores of Transylvania [6], who had sent a sample of this ore for confirmation by Klaproth. The orator, who delivered the memorial speech for Klaproth, before the Berlin Academy in 1819, was wrong when he was carried away with the power of his rhetoric and said: "Klaproth increased the number of elements with which the Lord God created the earth, by four" [7].

Klaproth made many contributions to various periodicals, most of them giving an account of the analysis of a single mineral. He also published his collective results regularly in book form under the title : Beitrdge zur chemischen Kenntniss der Mineralkorper, and this work extended to six volumes. The first of these was published in 1795, and the last in 1815, and in them Klaproth recorded the analysis of minerals originating from all parts of the world. In his books Klaproth departed from the earlier procedure of stating the experimental details very briefly, and often of publishing only the result without the inclusion of any relevant data such as sample weight, weight of precipitate, etc. He describes every step in the procedure in great detail, and in the introduction he explains his reason for doing so.

For those who want to repeat my experiments, I have written the procedure in as great detail as possible without exposing myself to a charge of loquacity. Those who are acquainted with this topic will perhaps recognize my intention, that is to find simple and reliable procedures for the analysis of minerals [8]. In another book he states, the experiments must be carried out in such a manner that if they are repeated by other chemists, who work with the same accuracy, then the result will always be the same [9].

An example of the methods of Klaproth are now given, without the introduction. It concerns the analysis of zoisite Chemical test: the specific weight of the ore is 3300. When heated on a carbon block with a blow pipe it shows a foam-like effervescence, and the color of the ignited part becomes reddish and it is transformed into a fine powder. During the course of the ignition the loss is insignificant.

If his results differed much from 100 per cent, then Klaproth searched for the cause of the divergence, and in this way he discovered new elements or found unsuspected components. In this way he found that potassium occurs not only in vegetables, but also in minerals. When examining the mineral leucite he found that there was a 21 per cent discrepancy in the total after the determination of aluminium oxide and the silicon dioxide. This was far greater than the possible experimental error, so he tested for the presence of borax, phosphoric acid and other less frequent components, but could not detect anything. Finally he evaporated and crystallized the residue remaining after the

separation. The shape of the crystals formed was quadratic, and they did not affect litmus, nor were they affected by ammonia nor soda solution. Klaproth noted, however, that the taste of the crystals was similar to potassium chloride, so he evaporated with sulfuric acid and was able to obtain crystals of potassium sulfate, and potassium nitrate crystals with nitric acid. This established the presence of potassium in this mineral. He also discovered that this gives a precipitate with tartaric acid, which upon ignition forms potassium carbonate [11]. As a result of this discovery he proposed to change the now obsolete names alkali vegetable (Pflanzenalkali) and alkali minerale (Mineralalkali) for natron and kali [12], which unfortunately were accepted neither in the French nor in the English languages.

Klaproth also originated the technique of alkali fusion, for which he used silver vessels. He also mentioned the use of platinum vessels in connection with the fusion with soda [13]. An indication of the exactness with which Klaproth carried out his analysis, can be judged from the fact that he carried out an analysis of the composition of the mortar he used to grind his samples, and thus found it was composed of almost pure silica. Also, after he had ground his sample for analysis he re-weighed it to ensure that it did not contain any of the material from the mortar, and if there was any increase in weight, then he subtracted an equivalent amount from the silicic acid content. Another important point that Klaproth was the first to note was that precipitates must be dried or ignited to constant weight, and in order to obtain the high temperatures sometimes required, Klaproth used the furnaces of the porcelain factory in Berlin [14].

It can be clearly seen how Klaproth developed his own ideas on stoichiometry. In the course of a silver ore test in 1795 he reduced silver chloride to silver metal, and he also reduced hydrated antimony oxide with potassium carbonate and carbon to pure antimony, and weighed them both in the metallic form [15]. Later he left out the reducing process, but still carried out an occasional reduction as a control test. For example, he dissolved 100 gr of antimony in 4 parts of hydrochloric acid and added some nitric acid to it, and after diluting with water found that he had obtained 130 gr of antimony lime (oxide). Using this proportion he calculated back his results to give metallic antimony [16]. After a while he must have realized that the control tests were superfluous as the results obtained were constant, so that in the last volume of his book he simply records that a certain weight of precipitate corresponds to a definite weight of metal or oxide. Moreover, he used these conversion factors for identification purposes.

An ingenious example of this is the proof that the mineral strontianite contains strontium and not barium. He placed 100 gr of strontianite in a small dish on the pan of a balance and saturated it with a weighed amount of hydrochloric acid. To the other pan of the balance he added an equal amount of hydrochloric acid. After the evolution of carbon dioxide was complete the weight of the sample was only 70 gr, therefore 30 gr of carbon dioxide had been evolved. If the substance had been barium carbonate then the weight of carbon dioxide evolved from 100 gr of sample would only have been 22 gr. The other proof he applied was that 100 gr of strontianite when treated with sulfuric acid formed 114 gr of strontium sulfate, of which 2??/2 gr were soluble in 8 oz of hot water, whereas of the amount of barium sulfate formed from an equal amount of barium carbonate, none was soluble in hot water.

Klaproth also changed the established methods of water analysis, wherever possible entirely omitting the separations based on fractional crystallization ... because that does not give a sure result. So I have devised a more reliable method which first of all involves the saturation of the free mineral alkalis with acid, and then

I decompose the neutral salts which are formed with a suitable reagent; at the same time I carry out a trial experiment in order to make clear the relationship, and on the basis of this I calculate the result [17].

An example of his trial experiment is as follows:

(a) He ignited 1000 gr of freshly crystal-

lized sodium carbonate on a sand bath when 363 gr of dry powder were formed.

(b) 100 gr of this saturated 382 gr of a sulfuric acid solution, which contained 1 part of acid (density 1.85) and 3 parts of water.

(c) The weight of Glauber's salt formed, after evaporation and drying, was 132/2 gr.

(d) 1000 gr of crystallized Glauber's salt, after ignition, formed 420 gr of dry salt.

(e) 100 gr of this when precipitated with barium acetate gave 168 gr of barium sulfate. Therefore 1000 gr of barium sulfate are equivalent to 595111, gr of water-free Glauber's salt.

(f) 100 gr of rock salt are equivalent to 2331/2 gr of silver chloride, therefore 1000 gr of silver chloride are equivalent to 4281/4 gr of sodium chloride.

After this he added sulfuric acid to the water, until it was just saturated (neutralized), and then precipitated the sulfate with barium acetate, and subtracted the amount corresponding to the added sulfuric acid from the weight of the precipitate. Then he precipitated the chloride with silver nitrate, and after filtration evaporated the filtrate and dissolved the residue in hydrochloric acid. Lime was precipitated from this solution with ammonium carbonate, and the iron with potassium ferrocyanide solution. The insoluble residue was silicic acid. On an analysis of 1 cubic inch (290 gr) of Karlsbad water, Klaproth obtained 39 gr of mineral alkali (Na2CO3), 345/8 gr of rocksalt, 701/2 of Glauber's salt, 21/2 gr of of silicic acid and 21/2 gr of iron.

For reasons of space, Klaproth's analytical methods cannot be described in their original detail. When examining silicate ores he separated the silicate after fusion by repeated evaporation with hydrochloric acid; he then separated the metals with ammonia and, finally, he precipitated magnesium in the form of the hydroxide. Ores containing sulfides he dissolved in nitric acid and filtered the separated sulfur, which he determined by ignition. He also questioned whether part of the sulfur does not form sulfuric acid during the solution process. He determined the sulfur content of a silver ore by this method, and then determined the sulfate-content separately, but was unsure whether any of the sulfate had been formed from sulfur. As the dissolution process was rather slow, and as only a very small amount of nitrous fumes was evolved, he considered it unlikely. In order to solve the problem he determined the sulfate after dissolution of the silver in hydrochloric acid when no oxidation of the sulfur could take place, and found that this result corresponded satisfactorily with the former, so he concluded that the nitric acid does not change the sulfide into sulfate [18].

Klaproth attempted a fusion of tin oxide, similar to the Freiberg method; he mixed the finely powdered cassiterite with an equal quantity of sulfur, and heated the mixture in a glass retort on a sand bath. However, the experiment was not very successful, so he repeated it using potassium hydroxide to fuse the sample [19]. He also observed the molybdenumblue reaction, when he treated molybdenum ores in hydrochloric acid medium with tin [20]. He hydrolysed iron with sodium succinate in the presence of manganese and aluminum [21], and then precipitated the phosphate and arsenate as the lead salts, and the chromium as silver or mercury chromate. The mercury was removed from the latter by ignition, and the chromium weighed as the oxide [22 ].There was no reference to the use of hydrogen sulfide in Klaproth's work, but he makes one reference to the use of ammonium sulfide for the identification of antimony [23]. Klaproth applied the corrosive action of hydrogen fluoride as a test for fluoride ion. He also utilized it for making glass micrometers for astronomical purposes [24]. Finally, we can see how the analytical data of Klaproth compare with present-day values (Table 7).

Louis Nicolas Vauquelin (1763-1829) was a peasant child, who also became an apprentice pharmacist at the age of 15. Later he went to Paris and worked as a laboratory assistant to Fourcroy, the famous chemist. He soon progressed from laboratory technician to become the co-worker of Fourcroy, and in 1791 he was elected a member of the Academy. He became a Professor of the College de France, and later at the University. He was the

discoverer of beryllium and chromium, but in addition to his research he was engaged in the production of chemicals on an industrial scale. The novelist Balzac portrays him as a scientist and industrialist in one of his novels [251. His chemicals were in great demand because of their purity and reliability, so that Vauquelin can be regarded as a pioneer in the production of analytically pure chemicals.

The work of Vauquelin is similar to that of Klaproth in that he analyzed a large number of minerals by methods similar to those of Klaproth, except that there were fewer original methods. Vauquelin studied the reactions of chromium and chromate very thoroughly; he found that chromium becomes yellow when fused with alkali, and that this solution gives a red precipitate when treated with mercury, and a yellow precipitate with lead; and that the addition of a tin chloride (stannous chloride) solution causes the solution to become green again.

## 6.5 Isomorphism & Dimorphism[665]

**REWORK:** The studies an crystallography being made at this time commonly held that identity of crystal form implied identity of composition. This principle had been enunciated by Haüy, the founder of crystallography, and it had many adherents, in spite of certain exceptions which had been observed. Klaproth in 1788 established the chemical identity of calcite, which occurs in the rhombohedral form, and aragonite, which occurs in the rhombic form (both are $CaCO_3$). In 1816 Gay-Lussac observed that crystals of potassium alum grew normally in a solution of ammonium alum, and about the Same time Gehlen succeeded in preparing typical alum crystals from a sodium-containing solution. In 1817 J. N. von Fuchs called attention to the similarity of crystal forms in aragonite, strontianite ($SrCO_3$), and cerussite ($PbCO_3$).

lt was Eilhardt Mitscherlich (1794-1863) who clearly established the relationship between chemical composition and crystalline forms. This was formulated in his law of isomorphism which was published after work done in 1819. In order to determine if crystalline form depends upon the chemical nature of the elements, he studied salts of the phosphates and arsenates. (Berzelius had already established the close relationship of these two Sets of saits in properties.) Mitscherlich found that the phosphates and arsenates each formed three distinct series of salts, and he reported that "every arsenate has its corresponding phosphate, composed entirely in the same proportions." He observed similar analogies in the various Sulfates and carbonates.

The law of isomorphism, which states that compounds which crystallize in the same form are similar in chemical composition, was well received. Mitscherlich recognized that similarity in chemical composition resulted in approximate rather than absolute isomorphism. Supporting data accumulated rapidly.

Mitscherlich's career in chemistry was delayed by his early interest in Oriental philology. While he was a student at Göttingen he came under the influence of Friedrich Stromeyer (1776-1835), noted for his discovery of cadmium in 1817, and for his early support of laboratory instruction in chemistry. Mitscherlich went to Berlin in 1818 for further studies in chemistry in the laboratory of H. F. Link, the botanist. It was here that he began his studies an arsenates and phosphates of potassium and confirmed Berzelius' reports regarding properties and composition. In starting his work an crystals he received instruction from Heinrich Rose's brother Gustav, mineralogist at the University of Berlin. The promising nature of Mitscherlisch's work led to his being invited to work in Berzelius' laboratory in Stockholm.

Soon after his return from Sweden Mitscherlich was appointed to the chair of

[665] Further historical information may be found in: Aaron J. Ihde., *The development of modern chemistry*. New York, Evanston, & London, Harper & Row Publishers, 1964. xii, 851 p., notes, illus., index. [Isomorphism and dimorphism, p. ??-??.] • E.M. Melhado., "Mitscherlich's discovery of isomorphism," *Historical Studies in the Physical Sciences*, **11** (1980), p. 87-123. • H.-W. Schütt., *Die Entdeckung des Isomorphismus. Eine Fallstudie zur Geschichte der Mineralogie und der Chemie*. Hildesheim, Gerstenberg Verlag, 1984. [1]-324 p., biblio., indexes. [History of the discovery of isomorphism and its impact on chemistry and mineralogy.]

chemistry, once held by Klaproth, at the University of Berlin. Here he continued his researches and wrote his *Lehrbuch der Chemie* (1829-1830). In his crystallographic studies he observed the variation in thermal expansion along dissimilar axes of a crystal, and the different crystal forms of sulfur. The property whereby a given substance could have more than one crystal form he called dimorphism. In 1827 he prepared selenic acid and showed that the selenates are isomorphous with the Sulfates. Later he demonstrated isomorphism in the manganates, chromates, and sulfates, and the permanganates and perchlorates. The isomorphism of the two latter salts revealed the composition of perchloric and permanganic acids.

Mitscherlich utilized the isomorphism of the sulfates and selenates to determine the atomic weight of selenium ; he reasoned that sulfate and potassium selenate have identical atomic ratios, except for the atom of sulfur in one, and of selenium in the other. As Table 6.3 shows, the weights of sulfur and selenium combined with equal weights of potassium and oxygen thus are 18.39 and 45.40 respectively. Since the atomic weight of sulfur is 32, that of selenium must proportionately be 79.

Berzelius meanwhile used the law of isomorphism in connection with his atomic weight estimations. The isomorphism of sulfates and chromates led him to revise the formula of green chromic oxide from CrO3 to Cr2O3; he assigned the formula CrO3 to chromic anhydride. The isomorphism of chromic oxide with the oxides of aluminum, iron, and manganese enabled him to assign correct formulas to the oxides of these metals. This led to his halving the atomic weights of these metals that he published in 1818. He subsequently halved the atomic weights of the other metals as well, thus bringing the results into accord with the law of Dulong and Petit. However, there were four exceptions. In the Gase of silver and cobalt, he doubted the validity of the law; and in the Gase of sodium and potassium, no specific heats were available.

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Already in 1815, J.N. Fuchs had observed that in gehlenite iron and calcium could mutually replace each other; he also pointed out the analogy with potassium- and ammonium alum. Four years later, E. Mitscherlich observed the similarity in crystal form of the potassium and ammonium salts of arsenic and phosphoric acid. Several investigators afterwards concerned themselves with the problem of isomorphic replacement of elements in crystals and proposed hypotheses for an explanation of the discoveries. However, a final solution could only be reached after M. von Laue's discovery of X-ray diffraction (for which he received a Nobel prize, in 1914) and the fuller interpretation thereof by W.H. Bragg and his son W.L. Bragg, in the years 1912–1913. This made possible the determination of the atomic struc-ture of solid substances. But it took some time before geochemists realized the importance of this discovery. When the last edition of Clarke's The Data of Geochemistry appeared in 1924, it contained nothing about crystal-structure determinations. Once more, it was V.M. Goldschmidt who saw the importance of crystal chemistry, and in particular, the importance of ionic radii for geology, which is so much a science of solids. The entry of any atom or ion into the lattices of crystals was found to depend upon its size. The particles dissolved in a magma or in an aqueous solution are thus sorted by the lattices of crystallizing minerals according to their sizes, which can be defined with sufficient accuracy by their atomic or ionic radii. Goldschmidt found that standard values of these radii could be determined for the various particles which occur in crystal structures; the standard state chosen by Goldschmidt and later adopted by other scientists being that of the ions in a lattice of the sodium-chloride type (Goldschmidt, 1923, 1924, 1954).

## 6.7 Pseudomorphs[666]

[666] Further historical information may be found in: Si Frazier., "Pseudomorphs," *Journal of the Geoliterary Society*, **??** (2004), p. ??-??. • Max Johs., "Pseudomorphososen ein kurzer geschichtelicher Überblick," *Lapis*, **6** (1981), no. 11, p. 36-37. • Georg Schulze., "Die Entwickelung der Lehre von den Mineral-Pseudomorphosen." *Jahresbericht des Neustädter Realgymnasiums zu Dresden* (Dresden, C. Heinrich, 1891), pp. 3-23. • G. Spiess, "Zur Geschichte der Pseudomorphosen des Mineralreichs." *Leopoldina*, **14** (1873?), pp. ??-??.

Every species of mineral when crystallized has a distinct and characteristic form. In the 18th century, when the concept of mineral chemistry was developing there were sometimes noticed specimens that had the form both as to the angles and general habit of a certain species, and yet differed from that species entirely in chemical composition. It was also observed that although the outward appearance showed a complete crystal, the internal structure was often granular, or waxy with no distinct cleavage. Such crystals are today called pseudomorphs (from the Greek *pseudo*=false+*morph*=form) and owe the existence to their original mineral being transformed through natural processes to a new compound. The new substance is said to be a pseudomorph after the original mineral.

Among the first to write a description of a pseudomorphic mineral is Romé de L'Isle, who described the over crustation of galena and pyrite by quartz which consequently gave quartz the shape of the other minerals. He furthermore observes in metallic minerals the shape of another mineral and suspected that such transformations were similar to the formation of petrified wood or other fossilized animal bodies where by the form remains eventhough the the material is completely transformed. Romé wrote:

> This must make feel how much the connoissance forms suitable for différens mixed can more jetter of day on the nature of these mixed one, since the forms often indicate the origin of certain substances to us which of all that they possédoient in a former state preserved only this only character.[667]

In another section Romé describes the well known pseudomorphs of galena after pyromorphite from Zschopau, Germany as a special type of lead ore, *mine de plomb noire cristallisee*. He adds, however, that it seems to be the product of decomposed green pyromorphite and he expresses the opinion that the original mineral has been converted to galena by the action of hydrogen sulfide gas.[668]

Around this time Abraham Gottlob Werner also took notice of pseudomorphs. He recognized that there was a substantial difference between authentic crystals and their pseudomorphic form. He could only explain them as the product of some unknown mineralizing force. Therefore in his descriptive mineralogy he placed these disquised minerals immediately after what he considered authentic crystals. In 1792 the renowned author and enthusiastic mineral collector Wolfgang Goethe proposed the term *Afterkrystallen* to generally describe this class of mineral.[669] Werner together with other early German researchers such as Estner, Hausmann, Hoffmann, and Breithaupt soon adopted the term.

However, in 1801 René Just Haüy first introduced the term pseudomorph to mineralogical science with the following statement:

> There is a third order of concretions, which we will call pseudomorphoses, i.e. bodies which have a false and misleading figure, because the substances which belong to this order present in a recognizable manner very foreign forms which they in some fate concealed with other bodies which swage them received nature.[670]

Further on, Haüy observes:

> One finds some substances of this reign (mineral kingdom) in crystalline forms that is borrowed, and it is rather probable, that at least in certain cases, the new substance gradually replaced that which yielded the place to it, as one thinks of the replacement of petrified wood.[671]

[667] J.B.L. Romé de L'Isle, *Cristallographie*, **1**, 1783, p. 93: "Ceci doit faire sentir combien la connoissance des formes propres à différens mixtes peut more jetter de jour sur la nature de ces mixtes, puisque les formes nous indiquent souvent l'origine de certaines substances qui de tout ce qu'elles possédoient dans un état antérieur n'ont conservé que ce seul caractère."

[668] Romé de L'Isle, *Cristallographie*, **3**, p. 400.

[669] Johann Grim and W. Grim, *Deutsches Wörterbuch*. Neubearbeitung Herausgegeben von der Akademie der Wissenschaften der DDR. Leipzig, S. Hirzel Verlag, 1986, vol. 2, col. 17, "Afterkrystall".

[670] R.J. Haüy, *Traité de Minéralogie*, **1**, Paris, 1801, p. 140: "Il existe un troisième ordre de concrétions, que nous appellerons pseudomorphoses, c'est à dire corps qui ont une figure fausse et trompeuse, parce que les substances qui appartiennent à cet ordre présentent d'une manière très reconnoissable des formes étrangères qu'elles ont en quelque sort dérobés à d'autres corps qui les avoient reçues de la nature."

[671] Haüy, *Traité de Minéralogie*, **1**, Paris, 1801, p. 143: "On trouve quelques substances de ce règne (règne minéral) sous des formes cristallines qui ne qu'empruntées, et il est

Because of Haüy's stature in mineralogical science, "pseudomorph" was the term soon adopted by reseachers outside Germany, which lagged sometime in accepting it.

In 1815 Werner's Bergakademie colleague Johann August Friedrich Breithaupt was the first to thoroughly study these interesting mineralogical formations, publishing his researches under the title, *Uiber die Ächtheit der Krystalle* (On the Authenticity of the Crystals).[672] In his book, Breithaupt recognized different types of pseudomorphs including those instances where there had been a gradual removal of the original material and simultaneously a replacement with the new mineral without any chemical reactions occurring between the two species. He also recognized alteration pseudomorphs where the original material had been changed to a different mineral species by the loss or addition of another chemical ingredient. For example, the loss of oxygen is the cause for native copper to form in the shape of cuprite crystals and the addition of carbon makes cuprite alter to malachite. Breithaupt's early interest in pseudomorphism foreshadowed his most important work and the research he is best remembered for today, mineral paragensis (see §6.8). After Breithaupt other researchers would begin to focus their attention on psuedomorphic minerals.

In the year 1816 a chemical text of Johann Ludwig Carl Gravenhorst appeared,[673] in which he focused his research at arriving at an understanding of the transformation process. He believed the transformation to be a gradual transition from one substance to another based upon enviromental conditions. Unfortunately, the writing is so obscure that his innovative ideas were overlooked by mineralogists of the time.

Johann Friedrich Ludwig Hausmann deviates little from Breithaput in his opinion about pseudomorphosen.[674] He differentiates likewise three kinds of "after-crystals", and recognizes that they were formed by a chemical transformation of the original crystal.[675] In his largest class, which he calls metamorphic crystals, he notes that the specimens retain the shape of the original material perfectly, being fully transformed, but are usually not as smooth and lusterous as the original due to a much more porous surface. In his two other types, Hausmann observes that one is formed by the original mineral being coated and this material filling out, leaving a core of the original mineral. In other observations, he recognizes how a coat wraps around a crystal that is then destroyed, leaving an empty area that can in some instances be filled by another totally different mineral. This formation process leaves a distinctive specimen showing impressions of crystals.

Friedrich Mohs, one of the most important pupils of Werner, and his successor as rofessor of the Mining Academy in Freiberg, is the first to differ substantially from his contemporaries with regard to pseudomorphs. He thinks that the pseudomorphic crystals principally form by first being an encrustation on the original mineral, which is in time is dissolved away, and the resulting shell is then filled in by the same mineral as the encrustation.

> In this case, the shape which the mineral assumes is not a consequence of the properties inherent in the mineral, or peculiar to its nature, but it merely belongs to that space serve as support for this individuals.

[676] In some cases, he also believed that pseudomorphs formed from the loss of chemicals in the minerals composition, usually sulfur.

Carl Friedrich Naumann[677] agrees with Mohs in his evaluation of the space

assez probable, qu'au moins dans certains cas, la nouvelle substance s'est substituée graduellement à celle qui lui a cédé la place, comme on pense que cela à lieu pour le bois pétrifié."

[672] J.A.F. Breithaupt, *Uiber die Ächtheit der Krystalle*. Freiberg, 1815.

[673] J.L.C. Gravenhorst, *Die anorganischen Naturkörper, nach ihren Verwandschaften und Uebergangen betrachtet und zusammengestellt*. Breslau, 1816.

[674] J.F.L. Hausmann, *Untersuchungen über die Formen der leblosen Natur*. Göttingen, bei Bandenhoeck und Ruprecht, 1821. viii, 677, [1] p., 16 folding plates (crystal drawings).

[675] Hausmann, *Untersuchungen*, 1821, p. 667.

[676] Friedrich Mohs., *Grundriß der Mineralogie*, Berlin, **1** (1822), p. 316-320.; *ibid.*, *Treatise on mineralogy*, translated by Wilhelm Haidinger. Edinburgh, **1** (1825), p. 258-263.

[677] Naumann, *Lehrbuch der Mineralogie*. Berlin, 1828, p. 209.

filling pseudomorphoses. He recognized three categories.

I. The "Umhüllung-Pseudomorphosen", or enveloping or encasing pseudomorph. It usually is applied to the case where a crystal is encrusted by another mineral and then the crystal is later dissolved away, either partially or completely. This type of psuedomorph forms commonly as quartz after calcite, and is today often called a perimorph (the new mineral is on the periphery of the first one).

II. The "Ausfüllungs-Pseudomorphen", that is literally a filling in or filling up pseudomorph, where one mineral fills in the space left by another crystal.

III. The "Metasomatish-Pseudomorphosen", which is the almost similtaneous replacement of one mineral with another. It is the principal method of ore deposit formation.

Naumann continued to review and evaluate the latest theory of pseudomorphs in the many editions of his popular and influential textbook, *Elemente der Mineralogie.*[678]

Wilhelm Haidinger provided substantial knowledge to pseudomorphs through a series of descriptive papers that he published through out his career.[679] He concentrated his research on the chemical processes that formed the pseudomorphs and especially the effect of oxygen, carbonic acid and water in the process. In 1827, he conclusively showed that some mineral psuedomorphs are formed by the alteration of the original mineral from the outside in. For example, magnetite altering to haematite. In particular Haidinger's work contributed early on to drawing attention to the importance of pseudomorphism in geochemical processes in the earth's crust and the formation of mineralized deposits.

František Xaver Maximilian Zippe believed that the pseudomorphs were created with in the earth by chemical decomposition.[680] He assumed this was some how influenced by the galvanic rivers, and he imagines the process. If a pyrite cube ($FeS_2$) is protected by the surrounding rock and comes into contact with water in a chlorinated state, then the sulfur compound is not changed. On the other hand, if the penetrating humidity acts as a galavanic conductor to the surrounding rock then elements in the pyrite are replaced either partially or completely, and the pyrite changes to other hydrous iron oxides, such as limonite ($2Fe_2O_3$) • $3H_2O$).

A substantial writing on pseudomorphs appeared in 1841 with the publication of Georg Landgrebe's *Ueber die Pseudomorphosen im Mineralreiche.*[681] In his forward Landgrebe writes that mineralogy has no field of study more interesting. Then after clearly defining what a pseudomorph is he divides the text into two large parts. The first covers mineral pseudomorphs and contains sections on mineral casts and mineral metamorphosis through chemical exchange. In the second part Landgrebe theorizes on the chemical transformation that occurs to create petrified wood and fossilized bones and plants. Incorporated within the body of the text are all citations to pseudomorphs that the author uncovered while conducting a systematic review of both German and foreign mineralogical literature.

Landgrebe divides the second category metasomatishe into the following classes of pseudomorphs.

I. Formed by molding (Abformung)

A. Molding by being coated e.g., quartz encrusting calcite that then disappears.

B. By having the new mineral totally replace the original one (Abforming durch Ausfülung). e.g., the famous talc pseudomorphs after quartz crystals from Göpfersgrun, near Wunsiedel in Bavaria.

II. Formed by alteration (durch Umwandlung).

A. Alteration without gain or loss of new components (Umwandlung ohne Abgabe oder Aufnahme von Stoffen). e.g., aragonite altered to calcite

[678] First edition, 1846; 15th edition, 1907.

[679] Haidinger, W., "On the parasitic formation of mineral species, depending upon the gradual changes which take place in the interior of minerals, while their external form remains the same," *Edinburgh Journal of Science*, **9** (1828), p. 275-292; **10** (1829), p. 86-96; *Edinburgh Royal Society Transactions*, **11** (1831), p. 73-118; *Schweigger's Journal*, **55** (1829), p. 257-317; *Froriep Notizen*, **26** (1830), cols. p. 17-25, 36-40; "Notiz von einer neuen Pseudomorphose," *Prag, Jahrbuch des Böhmische Museum*, **1** (1830), p. 16-19.

[680] Zippe, "Ueber einige in Böhmen vorkommende Pseudomorphosen," *Verhandlungen der Gesellschaft des vaterländischen Musuems in Böhmen*, Prag, 1832, 43ff.

[681] G. Landgrebe, *Ueber die Pseudomorphosen im Mineralreiche.* Cassel, 1841.

B. Alteration with the loss of a component (Umwandlung mit Verlust von Bestandtheilen). e.g., laumontites loss of water turning it into a crumbling powdery mess.

C. Alteration with the addition of components (Umwandlung mit Aufname von Bestandtheilen) e.g., anhydrite altered to gypsum.

D. Alteration with exchange of components (Umwandlung mit Austausch von Stoffen) e.g., feldspar altered to cassiterite.

A few years later a more extensive and complete work appeared. Based upon previous research and augmented with the author's own observations Johann Reinhard Blum's *Pseudomorphosen des Mineralreichs* is the most comprehensive treatise on pseudomorphs ever published.[682] This book begins with a review of previous studies on the subject together with a discussion of the same, and the author's reasons for dividing the subject into the two broad classes of alteration pseudomorphs and replacement pseudomorphs. The text then presents detailed descriptions of the 263 known pseudomorphs, for which Blum provides a thorough discussion of previous research, rich references, and locality information. Through his writings Blum reenforced the importance of chemistry in several pseudomorphic processes, especially in the replacement process, which was shown later to be one of the principle processes involved in forming economic ore deposits. Blum maintained and heavily augmented the basic text over the next 36 years by the publication of four supplements that appeared in 1847, 1852, 1863, and 1879. Today, this work is still considered the classic, fundamental work on pseudomorphs, which has never been surpassed in its treatment of the subject. Interestingly, the collection of over 1,700 pseudomorph specimens Blum accumulated during his research was acquired in 1871 by Yale University where they may still be found.

James Dwight Dana wrote on pseudomorphism in 1845.[683] In the fourth edition of his famous *System of Mineralogy* he summarizes previous work in the area, and compiles a list of the pseudomorphs reported to that time.[684] He recognizes four distinct types of pseudomorphs.

1. *Pseudomorphs by alteration:* Those that formed by the gradual change of composition in a species, e.g., change of augite to steatite, or azurite to malachite.
2. *Pseudomorphs by substitution:* Those that formed by the replacement of a mineral which has been removed or is gradually undergoing removal, e.g., petrifaction of wood.
3. *Pseudomorphs by incrustation:* Those formed through the encrustation of a crystal which may have subsequently dissolved away; often the cavity afterwards is filled [or partially filled] by infiltration; e.g., change of fluorite to quartz.
4. *Pseudomorphs by paramorphism:* Those formed when a mineral passes from one [dimorphous] state to another e.g., change of aragonite to calcite.[685]

Causes of change in the crystals Dana principally attibutes to the solvent power of ordinary ground water, the reactions according to chemical principles, of the ingredients, dissolved in those waters, the process of gradual oxidation to which the crystals are liable, and the reaction of substances thus formed on the ingredients at hand, and the action of exhaling gases from the earth, with or without volcanic action. This opinon follows mainly the observations given in Bischof's extensive work.

The important German mineralogist and crystallographer, George Amadeus Carl Friedrich Naumann [1797-1873] defined a pseudomorph (1846, 96) as a "crystalline or amorphous body that without itself being a crystal shows the crystal form of another mineral."[686] He favored a more restrictive definition than that used by many of his colleagues: "The crystal forms of

[682] J.R. Blum, *Pseudomorphosen des Mineralreichs*. Stuttgart, 1843.

[683] Dana, J.D., "On pseudomorphism," American Journal of Science, 48 (1845), ???????

[684] J.D. Dana., *System of Mineralogy*. New York, 1854, p. 222-226.

[685] Dana., *System of Mineralogy*. Fourth edition. New York, 1854, p. 223.

[686] Naumann, *Elemente der Mineralogie*, 1846, p. 96: "so nennt man nämlich diejenigen krystallinischen oder amorphen Mineralkörper, welche ohne selbst Krystalle zu sein, die Krystallform eines anderen Minerals zeigen."

pseudomorphs are usually quite well preserved [erhalten] and easily recognized with sharp, well-formed faces."[687] He distinguished three different types of pseudomorphs.

1. Umhüllung-Pseudomorphosen
2. Ausfüllungs-Pseudomorphosen
3. Metasomatische Pseudomorphosen

Naumann attributed the formation of all pseudomorphs to two processes:

A. A new mineral coats the surfaces of a crystal that forms out ("hypostatische pseudomorphosen").
B. Transformation of a crystal into a new mineral ("metasomatische pseudomorphosen").

With the last type, he differeniates the same four groups distinguished by Landgrebe: 1. Hypostatishen Pseudomorphosen, 2. Exogenous Pseudomorphosen, 3. Amphigene Pseudomorphosen, and 4. Esogenen Pseudomorphosen.

By the middle of the ninteenth century, research into the processes of pseudomorphism was still not well known. Only the simplest mechanisms were clear, but transmutation of complex mineral compounds remained only conjecture. Clearly it required an extremely delicate chemical reaction to proceed inside the earth and that a solvent, usually thought to be water was involved. In addition, heat in the form of volcanic warmth, electrical forces, and other unknown qualities contributed to pseudomorphism. During that time research into chemical processes inside the earth were becoming important areas of study, leading to the development of the field of geochemistry.

In 1847 Karl Gustav Christoph Bischof began to publish his *Lehrbuch der chemischen und physikalischen Geologie*, which was completed in 1855.[688] This enormous work soon became the standard text in geochemical studies, and helped found the sciences of geochemistry and petrology. The first volume in particular is concerned with the various aspects water plays in the geological process and at the core of these processes are the mechanisms of pseudomorphism applied to rocks and minerals on a regional scale. In particular Bischof like Haidinger examined the effect of oxygen, water and carbonic acid on mineral alteration.

Another researcher who extended the research in to mineral alterations was Theodor Scheerer, who authored *Der Paramorphismus und seine Bedeutung in die Chemie, Mineralogie, und Geologie*[689] Here Scheerer differentiated a peculiar condition that he called 'paramorphism' where a mineral species has a dimorphous state that because of temperature differences passes from one mineral species into another. For example, he describes a natrolite crystal from Norway that normally would be an orthorhombic mineral but had an exterior form that was monoclinic in habit. Other examples are the change of aragonite to calcite (both $CaCO_3$) at a certain temperature or the paramorphs of rutile after brookite (both $TiO_2$) from Magnet Cove, Arkansas.

In 1855, Gustav Georg Winkler published his *Die Pseudomorphosen des Mineralreichs.*[690] It is a cclear and concise review of pseudomorphism, containing a critical summation of all facts and explanations pertaining to the phenomena as it relates to the mineral kingdom. Winkler recognizes two types of pseudomorphism. The first, produced principally from atmospheric effects, causes the original material to be altered. The second, produced through mineralizing solutions, replaces the orginal mineral with a new mineral that is carried in the solution. The book describes specific replacements, gives commentary of the viewpoints of Blum, Haidinger, Landgrebe, and others, and contains a large descriptive section.

Winkler organizes pseudomorphs into a classification system based upon if the mineral is metallic or non-metallic. His categories are summarized below:

I. Pseudomorphosen of the non-metallic minerals.

[687] *ibid.*, "Diese Krystallformen der Pseudomorphosen sind meist sehr wohl erhalten und leicht erkennbar, ja zuweilen ganz sharfkantig und glatt."

[688] K.G.C. Bischof, *Lehrbuch der chemischen und physikalischen Geologie.*

[689] T. Scheerer, *Der Paramorphismus und seine Bedeutung in die Chemie, Mineralogie, und Geologie.* Braunschweig, 1854.

[690] G.G. Winkler, *Die Pseudomorphosen des Mineralreichs.* München, 1855. vi, 136 p.

A. Pseudomorphosen of first kind (fluor-spar after calcspar).
B. Pseudomorphosen of second kind:
a) Non-metallic minerals by non-metallic pleases (quartz after Calcspar),
b) Non-metallic minerals by metallic pleases (quartz after bleiglanz).
II. Pseudomorphosen of the metallic minerals.
A. Pseudomorphosen of first kind (brown iron stone after Eisenspat).
B. Pseudomorphosen of second kind:
a) Metallic minerals by non-metallic pleases (brown iron stone after Calcspar),
b) Metallic minerals by metallic pleases (brown iron stone after lead gloss).

The French chemist Achille Delesse in 1859 looked at pseudomorph formation from a purely chemical point of view.[691] Determinig the composition of inclusions contained inside the individual pseudomorphs, Delesse was able to show conclusively what the original mineral was, and derived a chemical process that would convert the original mineral to the new. His work was influential and fundemental to understanding pseudomorphic transformation.

Prior to the 1870's researches on mineral pseudomorphs were limited to observations that could be made on specimens seen with the naked eye. However, the introduction of both the petrological microscope and Ferdinand Zirkel's microscopical methods showed the great importance of pseudomorphism in the geological process, especially with relation to the formation of economic mineral deposits.[692] Zirkel's microscopic methods were collected together and first published as a dissertation by Franz Eugen Geinitz.[693] This led to a surge of investigations into pseudomorphic replacement as viewed through the microscope. Studies into the conditions that caused the original mineral substance to transformbecame important research. Geinitz was also able to show that the transformation occurs preferentially along the crystallographic axes.

Furthermore, Geinitz came to believe from the results of his investigations, that pseudomorphs come to existed based upon their chemical compostion, and that two possible methods of transformation were possible:

1. a casing, often by the new substance in an educated manner, with in-grown crystals already by around giving gesteinsmasse.
2. an actual, gradual displacement of the old substance by the new.

Much emphasis was placed on the meaning of the preservation of crystalline form during the transformation process. Using microscopic techniques Geinitz proved that the vast majority of pseudomorphs were created by the replacement of old material with new minerals, as opposed to displacement following casting or other filling out, and that replacement was a common method for ore deposits to form.

Geinitz gave the following version of how to organize the pseudomorphs based upon the chemical processes:

1. Pseudomorphs, developed without loss and without additional components (Paramorphosen).
2. Pseudomorphs resulting from loss of components (Apomorphosen). There is leaching and replacement at the same time.
3. Pseudomorphs, resulted from addition of components (Epimorphosen). There is no leaching, and the replacement takes place via the addition of components.
4. Pseudomorphs, resulting from the exchange of components, between the original and the pseudomorphic mineral (partial Allomorphosen).
5. Pseudomorphs, resulted from the total exchange of components between the original and pseudomorphic mineral (total Allomorphosen).[694]

Geinitz' research sparked in a large number of other studies to be prepared about mineral alteration. For the most part microscopes were employed to review how

[691] A. Delesse, "Recherches sur les pseudomorphoses," *Annals des Mines*, **16** (1859), p. 317-392. English translation, *Geologist*, 1860, p. 396-404, 450-453; 1861, p. 14-19.

[692] F. Zirkel., *Die mikroskopische Beschaffenheit der Mineralien und Gesteine*. Leipzig, 1873, and F. Zirkel., *Die Einführung des Mikroskops in das mineralogisch-geologische Studium*. Leipzig, 1881.

[693] F.E. Geinitz., "Studien über Mineralpseudomorphosen," *Neues Jahrbuch für Mineralogie*, 1876, 449-503.

[694] F.E. Geinitz, "Zur Systematik der Pseudomorphosen," *Tschermak's mineralogische und petrographischer Mittheilungen*, **2** (1880), p. 489.

crystals form within rocks and their method of alteration. For example, in 1876 and 1883, Johann Theodor Lemberg investigated and described the effects of aqueous solutions on mineral silicates.[695]

Max Bauer wrote on the pseudomorphs of calcite after aragonite, and made many worthy observations that threw light onto paramorphism.[696] He attributed the change to a molecular relocation with in the solid state of the crystal that over time converted the crystal system from othorhombic to trigonal, but kept the chemical compostion constant. In 1891, Bauer continued his studies of dimorphous pseudomorphs with his publication on the paramorphs of minerals with reference to that of rutile after brookite from Magnet Cove, Arkansas and of rutile after anatase.[697]

Henry Alexander Miers in 1896 published an admirable paper on 131 British pseudomorphs, never before described.[698] The list has general interest and illustrates the line of study regarding pseudomorphs. Miers follows these interesting determinations with a list of possible but insufficiently determined pseudomorphs comprising 56 examples.

Many other studies of specific pseudomorphs appeared partcularly among German mineralogists. However, relatively few general papers about pseudomorphs appeared after Geinitz' study. Among the general papers, Austin F. Rogers published a good account in 1910 that is still on one of the best in English on its subject.[699] Clifford Frondel in 1935 also contributed an authortative monograph based on an extensive study of pseudomorphs contained in the collections of the American Museum of Natural History in New York.[700] He was an authority on the subject and well acquainted with the previous literature about pseudomorphs, and his work is still perhaps the best available study in English on the subject.

## 6.8 Paragenesis[701]

Minerals are complex, naturally occurring chemical compounds that form within the interior of the earth over a period of time. As the mineral species form the conditions surrounding their formation such as temperature, pressure, composition of the mineralizing fluid that nurture the development of one species may change so that other species are deposited. These new conditions may also mean that previously deposited minerals are now replaced or altered to new minerals or in other cases dissolved away completely. The term 'paragenesis' refers to the time-successive order of formation of a group of associated minerals within a particular deposit. Since the great majority of mineral occurrences have been formed by several distinct periods of mineralization, the complete description of the paragenesis of a deposit involves establishing the order in which the constituent minerals have been formed and the sequence of reabsorptions and replacements that have occurred. To develop a theoretical profile of how minerals deposited, a full understanding of the physical and chemical processes present at the time of formation are required. It is not surprising then that although certain mineral species were almost always observed

[695] J. Lemberg., "Über Silicatumwandlungen," *Deutsche Geologisches Gesellschaft Zeitschrift*, **28** (1876), p. 519-621; *ibid.*, "Zur Kenntniss der Bildung und Umwandlung von Silicaten," *Deutsche Geologisches Gesellschaft Zeitschrift*, **35** (1883), p. 557-618.

[696] M. Bauer, "Über Pseudomorphosen von Kalkspath nach Aragonit," *Neues Jahrbuch für Mineralogie*, **1** (1886), p. 62.

[697] M. Bauer, "Pseudomorphosen von Rutil nach Brookite," *Neues Jahrbuch für Mineralogie*, **5** (1891), 16 p.

[698] H.A. Miers., "On some British pseudomorphs," *Mineralogical Magazine*, **11** (1897), no. 53, p. 263-285.

[699] A.F. Rogers., "Notes on some pseudomorphs, petrifications, and alterations," *Proceedings of the American Philosophical Society*, **49** (1910), no. 194, p. 17-23.

[700] C. Frondel., "Catalogue of mineral pseudomorphs in the American Museum of Natural History," *Bulletin of the American Museum of Natural History*, **57** (1935), p. 389-426.

[701] Further historical information may be found in: Frank Dawson Adams., "Origin and nature of ore deposits: An historical study," *Bulletin of the Geological Society of America*, **45** (1934), p. 375-424. • Walther Fischer., *Gesteins- und Lagerstättenbildung im Wandel der wissenschaftlichen Anschauung*. Stuttgart, E. Schweizerbart, 1961. viii, 592 p., illus., index. [Detailed history of petrology and the study of ore deposition.] • Victor Moritz Goldschmidt., *Die kontaktmetamorphose im Kristianiagebiet*. Kristiania, In Kommission bei J. Dybwad, 1911. ix, 483 p., 2 plates, maps, diagrams. [Reviews previous research into paragenesis.] • Paul Groth., *Entwicklungsgeschichte der mineralogischen Wissenschaften*, 1926, p. 194-211.

to be associated together, it was not until the chemical aspects of mineralogy were fully developed that the paragenesis process was fully conceptualized.

Typical of the late eighteenth century was the description by Jean-Baptiste Louis Romé de l'Isle of the metallic ores contained in his personal mineral cabinet. In his *Description Méthodique d'une Collection de Minéraux* (Paris, 1773) he gives the standard physical characteristics, localities, and mineral associations (i.e., paragenesis) for each specimen. However, he makes no connection between the associated minerals other than listing them. This was common to descriptive mineralogies of the period because by and large their descriptions were based on individual specimens separated from the environment in which they formed. This made it exquisitely difficult to recognize that there was a distinct sequence of processes that created the specimen. Therefore it was left to a group of researchers and writers who had lengthy, practical experience working in mines, and who recorded their observations in full descriptions of the mineral veins within the mines to accumulate the evidence that eventually compelled those simple lists to morph into the idea of mineral paragenesis. Early evidence that lead to building a theory of paragenesis was supplied by the authors of books describing ore deposits, and speculation as to how the ores formed inside the earth.

A professor at the Bergakademie in Freiberg, Johann Friedrich Wilhelm von Charpentier wrote in 1778 his excellent and pioneering book, *Mineralogische Geographie der Chursächsischen Lande* (Leipzig, 1778). In this work he set out the results of a long period of observation and study about ore deposits and their minerals. He gives an excellent description of the veins and other mineral occurrences of Saxony and the adjacent regions, and in the last few pages of the book discusses the question of the probable origin of the ores. He gives an admirable presentation of the facts gathered during his long years of mining experience. Charpentier considers in succession those observations that have a definite bearing on the question of the genesis of the ore deposits, and, based on them, he offers an explanation of their origin, which, he says, cannot be considered as more than a conjecture but which he believes represents the closest approximation to the truth attainable at that time.

Charpentier abandons beliefs the ancient believes and proposes that mineral deposits, including the veins were created by some alteration happening to the original country rock. He comes to this opinion based upon his long experience of first-hand observation of mineralized veins in the earth and notes that ores like cassiterite (tin) are distributed through their host rock like a huge three dimensional web. He envisions an ore deposit forms in a way analogous to the process that forms petrified wood. Petrified wood, he notes, was not silicified from the outside in, noting that had that occurred the hard silica would act like a shell around the woody interior. There apparently was some unknown process that changed the original wood to silica—a change Charpentier considers even more remarkable than the creation of the stock work of an ore deposit.

Carl Abraham Gerhard, who wrote in 1781 his *Versuch einer Geschichte des Mineralreichs* held that veins were open fissures which originated through great movements in the earth's crust as well as from other causes, and that they were filled by the action of waters dissolving material out of the surrounding country rock and depositing it in these fissures.

The famous and elaborate work on mining written by Friedich Wilhelm Heinrich von Trebra.[702] contains a small section that speculates on the genesis of ore deposits. He agrees with Charpentier that his speculation is only a theory and is open to many objections. Trebra believed ore bodies developed through "Gahrung" and "Faulniss", which literally translated means "Fermentation" and "Decomposition", respectively. This is an echo of the ancient beliefs that processes with in the earth were analogous to those inside a living body of

[702] Friedich Wilhelm Heinrich von Trebra., *Erfahrungen vom Innern der Gebirge*. Dessau und Leipzig, 1785.

an animal, and as an animals body was nourished by blood and other fluids contained in a circulatory system, so the earth was nourished by fluids circulating in its body. The central fire located deep in the earth supplied the energy to cause circulation to occur. Trebra notes that when some organic bodies like yeast come into contact with water, the mass undergoes substantial changes and ferments. In dead animals, when the body is exposed to air, they like wise substantially change through decomposition. It was thought that similar processes existed inside the earth, and that this was how ore deposits and veins formed. By the eighteenth century, the German miner's coined the terms "Gahrung" and "Faulniss" to describe the processes of ore and vein creation, which Trebra adopts in his writing. The modern terms, Metamorphism and Weathering, embrace most, if not all, of these natural operations. Trebra is silent, however, as to any theory regarding the possible sources for the minerals that filled the veins.

Abraham Gottlob Werner, the famous mineralogist, also set about to give a theoretical answer to the problem of ore formation and thus gave stimulus to the search for a solution. His *Von den Entstehung der Gänge*, published in 1791, more than previous similar works, made the study of vein formation an integral study in historical geology.[703] He adds some observations to the previously existing knowledge of the internal structure of the veins, the phenomena displayed at the intersection of different sets of veins, and the differences between the internal structure of veins and beds. However, it is Werner's new and novel theory of vein formation that caused his work to be widely studied. As the chief supporter of the Neptunist theory, which he had developed, and which theorized most rocks were created by being deposited in ancient oceans, he suggested that as the sediments settled from the ocean and became compacted as rocks, cracks developed in the mass due to the squeezing out of the water or other events such as earthquakes. Some of these open fissures would extend all the way to the surface, and if still located under the sea, they would be filled with waters of the great ocean. In such fissures the oceanic waters would lay undisturbed and would over time precipitate and crystallize the minerals that form a mineral vein or deposit. Werner did not believe that veins derived their metallic content from the country rock through the action of circulating waters, because the country rock in districts where metal-bearing veins occur, contains no traces of the metals which are found in the veins. This theory is not possible, because he says the first layer of material secreted along the walls of the fissure would make it impermeable to the passage of all further solutions. Werner's personal charm, however, must have been altogether remarkable. No other teacher of geological science either before or since has approached him in the extent of his personal influence or in the breadth of his contemporary fame, and his theory of ore deposition was widely studied. It was entirely disproved by the early nineteenth century, however. In fact, the Bergrath Friedrich Constantin[704] of Werner's own city, Freiberg, less than fifty years after the publication of Werner's *Neue Theorie*, writes that not only this theory, but Werner's whole system of geognosy, had completely broken down under the accumulation of a great body of newly discovered facts. For example, Forchammer, of Copenhagen, in an 1835 paper, detailed the results of a series of chemical analyses which showed that, contrary to the statement of Werner, minute quantities of the heavy metals were present in almost all rocks.[705] Forchammer correctly claimed that circulating ground waters made their way laterally into fissures, carrying materials in solution, and filled the fissures, thus giving rise to mineral veins, but he did not make the connection to a sequence of mineral depositions, and missed describing paragenesis.

The theory of paragenesis, or the association of minerals of common origin was sug-

[703] Abraham Gottlob Werner., *Neue Theorie von der Entstehung der Gänge*. Freiberg, 1791.

[704] Friedrich Constantin, Freiherr von Benst., *Kritische Beleuchtung der Werner'schen Gangtheorie*. Freiberg, 1840.

[705] [ Title Needed ] [ ]

gested as a general idea by the great Russian mineralogist Vasily Mikhaylovich Severgin in 1798,[706] who noted the significance of mineral associations — sphalerite and galena, for example — and developed a theory on the contiguity of minerals that he described as the occupance of two or more minerals in one place.[707] Even when a later Russian mineralogist, Dmitrii Ivanovich Sokolov, wrote a detailed textbook of mineralogy.[708] He correctly attributed the physical properties of minerals, including morphology, color, shape, luster, cleavage, hardness, to the chemical composition of the mineral. Like many mineralogists, Sokolov was interested in mineral associations, and discusses something like paragenesis in his textbook of mineralogy. The Russian insights into paragenesis remained unknown and unrecognized to European researchers, however. The theories of Werner had much more influence.

In his massive description of the mineralogy, geology, and mining of Saxony, Freiesleben provides an abundance of data regarding mineral associations actually observed in the mines, particularly the tin deposits.[709] In other countries concepts surrounding the importance of mineral associations were beginning to take root. Robert Jameson for example, in the second edition of his *System of Mineralogy* published in 1816 continues to give an account of the mineral associations when he describes the geographic situation that specific mineral species are known to occur. The Englishman W. Henwood in a series of writings between 1831 and 1846 presents descriptions of mineral associations observed in the mines of Cornwall.[710] Andrés Manuel del Río published many mineralogical papers related to Mexican mineralogy and geology, including work on the origin of mineral veins, the associations seen in sulfide minerals, and the effect of trace elements on a minerals physical properties, and polymorphism.

The French geologist G.A. Daubreé authored in 1841 a particularly important paper, in which he compares chemically the tin ores of Germany, England, and France, and notes that in all cases the tin ore (cassiterite) is always accompanied by minerals such as fluorite or ———— that contain the elements fluorine or boron.[711] At the time, it was generally accepted from laboratory experiments that there was a chemical affinity between silicon and tin. In his study, Daubreé concludes that fluorine and boron must impregnate the original host rock where the ore deposits formed, and when a mineralizing solution containing tin and silicon came into contact, cassiterite, quartz, fluorite, and the associated minerals were deposited. This theory was later expanded when it was shown that titanium was also present. Later, after paragenesis was firmly established, Daubreé's observations were shown to be correct, and that the tin containing minerals of Saxony had been formed from original sulphides ores that had been acted upon not by a metalliferous solution but by the penetration of flourine and boron gas penetrating from deep inside the earth. In 1843 Daubreé published an overview and description of the geology and mineralogical conditions of a large number of Swedish and Norwegian ores.[712] Again he recognizes the importance of the geological conditions in the formation of ore deposits. In this case, the type of host rock and the presence or absence of pegmatite material. The work formed together with Hisinger's topographical studies a valuable study of the mineralogy and geology of Sweden

[706] *Pervye Osnovania Mineralogii*, p. 85-86.: [**GIVE QUOTATION**]

[707] I.D. Sedletskii. "Акад. В.М. Севертин и учение о парагенезисе минералов. [Acad. V.M. Severgin and the study of the paragenesis of minerals]", *Vestn. As USSR*, **1** (1948). • I.D. Sedletskii. "Приоритет русского учехого В.М. Севергина в учехии о парагенезисе минералов. [Russian scientific priority of V.M. Severgin in the study of the paragenesis of minerals.], *Zap. Rostov State Univ.*, **11** (1948), no. 6.

[708] Dmitrii Ivanovich Sokolov., Руководство Къ Минералогіи.. St. Petersburg, 1832.

[709] Freiesleben., *Geognostische Arbeiten*, 1807-1815.

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[711] G.A. Daubreé., "Mémoire sur le gisement, la constitution et l'origin amas de minéral d'etain," *Ann. de Mines*, Paris, 1841.

[712] G.A. Daubreé., "Mémoire sur les déposits metalliféres de la Suede et de la Norwége," *Ann. de Mines*, Paris, 1843.

and Norway.

It was the long history of mining in Saxony that provided an extensive line of observations from which the German theorists could draw. In addition, there was by the middle of the nineteenth century an active study of the geology of central Europe being carried out and new observations were regularly being reported and published. Finally in 1849, the connection of mineral association was more generally explained by Johann August Friedrich Breithaupt in his *Die Paragenesis der Mineralien* (The Paragenesis of Minerals), that gave a formal name to the study.[713] This was by far Breithaupt's greatest contribution to mineralogy and to the developing study of ore deposit formation. Although as it has been shown some earlier researchers had noticed that there was some regularity in the association of different minerals, Breithaupt was the first to make a comprehensive study of the associations and emphasis their importance. Studying the minerals of the Schwarzenberg region, Breithaupt developed a classification of 20 mineral associations.

**[GIVE TABLE]**

Breithaupt's ideas received a great deal of observational and experimental support in the course of the nineteenth century. Tangentially the study of pseudomorph formation and other geochemical processes contributed greatly to understanding paragentic formation.

The importance of Breithaupt's work was immediately recognized by others, especially those researchers studying the emerging field of geochemistry. For example, Bischof in his important *Lehrbuch der chemischen und physikalischen Geologie* (Textbook of Chemical and Physical Geology) published between 1847 and 1855 discusses the importance of mineral associations, basing his observations on Breithaupt's work and other related publications. A.E. Reuss' work that describes the paragentic formation of minerals in Pribram in Bohemia clearly shows Breithaupt's influence. Ruess demonstrates that the main sequence of mineralization that started with galena, and progressed through sphalerite and barite, to the various carbonate minerals, like calcite. He recognized from the diversity of mineral mixes that multiple generations of mineralization occurred; however, Reuss missed connecting the formation of minerals with the surrounding geology.

It is the combination of geology together with the presence of mineralizing fluids that cause mineral species to develop. This was a large and complex concept to grasp, and a splendid early example of this complete approach was the examination of the silver ores of the Andrea Mountains of Saxony published in 1865 by H. Credner.[714] Credner is also credited with preparing the first modern geological map of Saxony and a study of the ore deposits of North America, which are the principal works of his career.

In the 1860s, Gustav Tschermak began a series of studies into petrology. This led him into the study of paragenesis of minerals in several granites, the quartz content of plagioclase, and the role of olivine in various rock types.[715] In fact, the study of mineral paragenesis was deemed important enough that Alfred W. Stelzner began teaching in 1860 a course in the subject at the Bergakademie in Freiberg.[716] In 1865, Geyer and Ehrenfriedersdorf published a study of South American silver minerals that included descriptions of their paragenesis.[717]

'Gang-formations' were observed by Breithaupt, which did not appear part of the main mineral deposit formation. Bernhard von Cotta in his *Erzlagerstättenlehre* (Ore Deposit Instruction) of 18????? was probably the first to call these occupance "contact ore de-

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posits", and their geology derived from eruptive or intrusive magma rock.

As a student of Breithaupt, Paul Groth paid particular attention to the paragenesis of minerals. In an 1885 monograph on the mineralogy of Dauphiny, Groth accounted for the dependence of axinite-epidote sequences in amphibole schists and of anatase-turnerite sequences in gneiss by the leaching of elements from the surrounding rock. He continued to develop paragenesis and his *Topographische Übersicht der Minerallagerstätten* (1917) that gave a general description of mineral deposts based upon geography was one of the best surveys of the time.

As for the paragenesis associated with pegmatites, the great Norwegian researcher W. Brøgger is of fundamental importance for his research on the chemistry of these interesting geological bodies, especially where they contact and interact with the surrounding rock. The first researcher to apply rigidly the laws of physical chemistry to the problems of mineral associations at contact zones between host rock and a magmatic heat source was the Norwegian geochemist Victor Moritz Goldschmidt who gave a full account of contact metamorphic processes in his important *Die kontaktmetamorphose in the Kristianiagebiet* (Kristiania, 1911). While discussing his own theories, Goldschmidt covers in detail all the earlier work in mineral associations and paragenesis. Even though his work is fundamentally geological in nature and outside the scope of historical mineralogy, the information presented was valuable to preparing the preceding historical presentation.

Paragenesis began to be viewed as a distinct process in all of geology and not limited to ore deposition. This had an important effect on not only mineralogy, but also geology generally. Mineral formation began to be viewed as one part of a much fuller geological process, that led to more efficient geological exploration. Geologists of all nations began to reevaluate and interpret the geological structure of their nation in new ways and with a broader spectrum of theories. In Scandinavia, the ore deposit and geological studies of W. Brøgger in the last part of the nineteenth century were part of this trend. Developments in petrology and various theories of rock formation allowed him to make new observations about the "Kristainiagebeit" formation of Norway. Previously, it had been studied by I.H.L. Vogt who showed in 1893 the silica rich intrusion to be enriched with a high percentage of heavy metal that were later deposited as concentrated formations of economic value along the contact zones of the intrusion.[718] This model could be applied to other geological formations through out the world, and as a result other formations of a similar nature were recognized. This led to an explosion of general studies of ore deposits, their formation, and a classification of their types, all ultimately based upon their paragenesis.

By the beginning of the twentieth century the concept of mineral paragenesis was firmly established. In fact, enough was known of the types of mineral formation that would occur based on the conditions of a mineralizing fluid such as a pegmatitic magma, that paragentic classifications of minerals were proposed in 1900 and 1908 by A. de Lapparent,[719] and in 1932 by F. Angel and R. Scharizer.[720] In addition, a number of important books on the subject of ore deposits were published: Emmons,[721] Kemp,[722] R. Beck, 1901,[723] A. Bereat, 1904-1906,[724] and F. Beyschlag,

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[720] Franz Angel and Rudolf Scharizer, *Grundriss der Mineralparagenese.* Wien, J. Springer, 1932. xii, 293, [1] p.
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1910-1913.[725] These texts are the foundation of modern economic geology theory, and they all are derived to some extent on the development of theories regarding mineral paragenesis.

## 7.0 Experimental Mineralogy

**REWORK:** In the 19th century the first attempts were made to create minerals and igneous rocks artificially. The different methods employed were classified by Fuchs, Fouque and Michel-Levy, and Bourgeois as follows:

1. Crystallization by fusion (simple fusion without solvents; fusion with solvents but without chemical reactions; fusion involving chemical reactions).
2. Crystallization by sublimation (simple sublimation; chemical reaction between volatile substances; reaction between volatile and non-volatile substances).
3. Crystallization by solution (solution without chemical action; chemical reaction of two liquids; reaction of liquids and solids).

Among the most interesting syntheses were: the laboratory production of marble from limestone (James Hall, 1801); the production of artificial quartz and orthoclase by the action of pure or slightly carbonated water under high pressure (Senarmont, Daubree and Friedel); the production of cassiterite (tinstone) and rutile by the action of water vapour on a chloride or fluoride (Daubree); the production of metallic sulphides by the action of sulphuretted hydrogen on a chloride (Durocher); that of orthoclase, albite, quartz, emerald and zircon, by chemical reaction in the presence of mineralizers (Hautefeuille); and finally the synthesis of rubies (Fremy, Feil and Verneuil, 1877-1891).

Fouque and Michel-Levy's elegant experiments on the artificial production of igneous rocks (1878-1881) helped to solve a number of outstanding problems. In particular, they helped to prove the impossibility of synthesizing granitic rocks by igneous fusion alone.

Experimental syntheses of inorganic chemical compounds have thrown much new light on the genesis and transformations of minerals in nature. By modifying the technique of H. de Senarmont (1851), R. Weil and R. Hocart (1951-1953) were able to study the formation of silver ore and of various sulphides and arsenides in greater detail. Other experimental studies have yielded important clues to the origin of certain microstructures observed in metallic ores. J. Morocewicz (1898), J. H. L. Vogt (1924), N. L. Bowen, W. Eitel, P. Grigoriev and O. F. Tuttle have done decisive work on the reproduc tion of magmatic minerals by the 'dry path'.

The role of water as a mineralizer, in the supercritical state and in the presence of alkali salts, which was first demonstrated by Friedel (1890-1891), was confirmed by G. W. Morey and Earl Ingerson (1937) and by C. J. van Nieuwenburg (1932-1935). Synthetic studies of argillaceous minerals were made by W. Noll (1935-1936) and R. Roy (1950-1961) .

Using the high temperatures and pressures produced by the detonation of explosives, A. Michel-Levy and J. Wyart (1938-1948) were able to reproduce various minerals associated with meta morphic transformations. Under different experimental conditions,

Mme Christophe-Michel-Levy (1953-1957) succeeded in producing a series of metamorphic silicates and in reconstructing a number of natural parageneses. J. Wyart and H.G.F. Winkler studied the metamorphic transformations of certain argillaceous rocks; S. Caillere, S. Henin and J. Esquevin succeeded in synthesizing the mineral constituents of phyllites.

On the whole, the experimental work has tended to confirm the observations of mineralogists and petrographers in the field.

## 7.1 Origin of Minerals[726]

From the earliest times, many theories were invented to explain how minerals came to exist. After chemistry had developed sufficiently,

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[726] Further historical information may be found in: D.P. Grigor'ev., *Ontogeny of minerals*. Translated from Russian by IPST staff. Translation edited by Y. Brenner. Jerusalem, Israel Program for Scientific Translation, 1965. v, [1], 250 p., illus. [The introduction contains an historical essay on the development of ideas about the origin of minerals.]

attempts were made to synthesis minerals, and this led to a better understanding of the processes that were needed for mineral formation in the earth. In particular, considerations of the effect of temperature and pressure on the mineralizing solutions has led from the 19th century until today's studies to a firm grasp of why minerals not only form, but why specific suites of species occur together.

### 7.1.1 Fluid Inclusion Studies[727]

**REWORK:** Fluid inclusions are small volumes of a fluid in a crystal. These fluids can be trapped for example along growth zones or crystal edges or in any imperfection of a crystal during growth as primary inclusions. When a mineral is fractured during growth syngenetic microcracks will be healed in the presence of a fluid which may be trapped as pseudosecondary inclusions. Any stress after crystal growth will lead to epigenetic fractures and secondary inclusions may be the result of their recrystallization. Primary and pseudosecondary inclusions will thus contain the fluid from which the host crystal has grown. Therefore they can provide information on the fluid composition of the corresponding environment (magmatic hydrothermal fluids, basinal brines, heated meteoric waters, etc.). But also secondary inclusions may provide information on the later geological history of a crystal.

The study of fluid inclusions has become a routine method for solving a wide range of geoscientific problems of different disciplines like petrology, structural analysis, or the genesis and exploration of ore or hydrocarbon deposits. It took, however, a long time to establish fluid inclusions as a reliable tool for answering geological questions. This paper refers to the historical development of fluid inclusion research from early observations to first experiments and introduces the work of the most important scientists in its historical context. Finally, some statistical data about the latest developments and a short outlook on the near future are given.

By their composition the majority of fluid inclusions are water-salt-gas mixtures with NaCl being the most important salt and CO2, CH4, and N2 as the most important gas species. In terms of thermodynamics a fluid inclusion represent a closed (isochoric) system which is defined by pressure (P), temperature (T), volume (V) and chemical composition (X). Two of these parameters (V, X) are fixed during formation of an inclusion while P and T remain variable after trapping.

At room temperature most fluid inclusions contain two phases, a vapour bubble and an (aqueous) solution. But other phase combinations as two immiscible liquids (liquid CO2 and water for example) with or without a vapour bubble are common as well. Additional solids may occur which are termed daughter crystals if they precipitated from the trapped solution. Halite is by far the most common solid phase observed. Figure 1 shows an example of a multiphase fluid inclusion with three daughter crystals (halite, sylvite, arcanite).

The aim of any fluid inclusion study is the reconstruction of the PTVX-properties. The most applied method is microthermometry which means the observation of individual fluid inclusions on a heating- and freezing stage under the microscope in the temperature range of-180°C (i. e. cooling with liquid nitrogen) to +600° C. After complete freezing (solidification) the inclusions are carefully warmed or heated and any observable phase change up to total homogenization (one-phase state) is recorded. Initial melting of any solid phase permits the identification of the involved aqueous and also gaseous systems (H2O-NaCl, H2O-CO2, CO2-CH4, etc.). Final melting temperatures (or temperatures of dissolution) point to the concentration of individual components in the corresponding system. The freezing-point depression of ice in aqueous inclusions, for example, is a measure for the total salt concentration (salinity) which

[727] Other historical information may be found in: Frederick Gordon Smith., *Historical development of inclusion thermometry*. Toronto, University of Toronto Press, 1953. [i]-iii, [1], 1-149 p., biblio., index. [Excellent, little known history of mineral inclusion studies.] • Robert Wiesheu and Ulrich F. Hein., "The history of fluid inclusion studies" (pp. 309-325), in: Bernhard Fritscher and Fergus Henderson, eds., *Toward a history of mineralogy, petrology, and geochemistry*. München, Institut für Geschichte der Naturwissenschaften, 1998.

is commonly expressed as weight percent NaCl equivalent. The tem-perature of total homogenization of an inclusion defines its density. Furthermore the homogenization temperature means the minimum trapping temperature.

A microthermometric investigation would begin with supercooling and complete freezing of the inclusion (E). During subsequent warming ice melting occurs until the last ice crystal disappears at the temperature of final melting (Tm) in D. Further warming means expansion of the liquid phase along the liquid-vapour cotectic curve until the vapour bubble disappears at the temperature of homogenization (Th) in B. After homogenization a small increase of the temperature by further warming would lead to a large increase of the inclusions' internal pressure along the isochore.

Inclusions in crystals are most probably documented for the first time in the fourth century by the Roman Claudian [c375-c404], who wrote down nine epigrams with the title De crystallo cut aqua tnerat.1 In the 11th century the Mid Asian scholar al-Bīrūnī [973-c1050] gave a first detailed description of fluid inclusions, but it was only in the second half of the 17th century that scientists used these observations for genetic interpretations of minerals and gemstones. Nicolaus Steno [1638-1686], the famous geologist and founder of the 'law of stratification', observed fluid inclusions along blue and white growth zones of chevron quartz.[728] He concluded that the crystal grew from the inner to the outer zones by precipitation from a solution and that the inclusions represent relics of this solution. This conclusion was problematic since it contradicted the Aristotelian tradition which interpreted quartz crystals as fossil icicles.

The first English description of fluid inclusions dates back to 1672 when Robert Boyle [1627-1691] reported a large moving bubble in quartz. He concluded that gemstones, like salt, originate from liquid and soft material because gemstones have crystal shapes and cleavages similar to that of salt crystals.[729] Like Steno he denied the origin of quartz from icicles. He argued that ice is less dense than water and therefore cannot contain water inclusions, whereas, according to his own calculations, the specific weight of quartz is 2.65 g/cm3.

Other scientists followed. Between 1702 and 1711 Johann Jakob Scheuchzer [1672-1733] published observations on vapour bubbles in quartz.[730] He favored the notion that quartz had its origin from water because of the fact that all water contains vapour bubbles. Generally, large inclusions attracted the attention of early naturalists (Dewey 1818; Dwight 1820; see Smith, 1953, for additional references). Besides pure descriptions there were first reports on the nature of the trapped fluid. Commander Deodat de Dolomieu (1792) may have been the first to report inclusions in quartz filled with petroleum.[731] Hayden (1819) described a new mineral, neocronite, that spread a terrible smell.[732] In fact the mineral turned out to be common feldspar containing H2S-bearing inclusions.

The first analytical and experimental work to establish the composition of specific inclusions was done in the early 19th century. Scipione Breislak [1750-1826], in 1818, analyzed petroleum inclusions in quartz.[733] Sir Humphrey Davy [1778-1829] opened inclusions by drilling under water, oil and even mercury and pipetted the released fluids for chemical analysis. Moreover, he was the first to observe fluid inclusions with a microscope.[734] In 1823 David Brewster [1781-1868] published two

[728] Steno, N. 1669. Prodromus de solido intra solidum naturaliter contento. Florenz: Stella.

[729] Boyle, R. 1672. Essay about the origine and virtues of gems. London, William Godbid.

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[731] Dolomieu, Deodat de. 1792. Sur de l'huile de pêtrol dans le cristal de roche et les fluides élastiques tirés dur quartz. Observation sur la Physique 42:318-19.

[732] [ Title Needed ] [ ]

[733] Breislak, S. 1818. Institutions géologiques. Translated from the Italian by P. J. L. Campmas. Milan, Impr. impériale et royale.

[734] Davy, H. 1822. On the state of water and aeriform matter in cavities found in certain crystals. Philosophical Transactions of the Royal Society of London 2:367-76.

papers about fluid inclusions in the Edinburgh Philosophical Journal.[735] He observed fluid inclusions containing a vapour bubble and two immiscible fluids and found out that the expansion of the second fluid (carbon dioxide, as he concluded later) was 32 times greater than the expansion of water. Brewster also reported for the first time daughter crystals within fluid inclusions and identified them as calcite. For his innovative pressure experiments he used rifle barrels as auto-claves which were the most stable vessels available at that time. The results of these investigations, including the work of William Nicol [1768-1851],[736] were used as very strong evidence to support the Neptunist theory that all crustal materials had their origin from ocean suspension or solution. Ongoing research added more details on fluid compositions. Jean-Baptiste Dumas [1800-1884], in 1830,[737] and Heinrich Rose [1795-1864], in 1839,[738] reported inclusions of an inflammable gas (CO2) in rock salt. Brewster (1845) observed the formation of daughter minerals upon heating of inclusions (i. e. retrograde solubility of carbonates)[739] and Robert Bunsen [1811-1899], in 1851, identified CH4 in rock salt from Wieliczka/Poland.[740]

The year 1858 marked a milestone in the history of fluid inclusion research. Sir Henry Clifton Sorby [1826-1908], "The Father of Microscopic Petrography",[741] published his paper On the Microscopical Structure of Crystals indicating the Origin of Minerals and Rocks (Sorby 1858). This paper was based on the four fundamentals: observation, experiment, theoretical interpretation, and application, and it presented the first systematics on fluid inclusions.[742]

Sorby was the first to propose that the gas bubbles present in most fluid inclusions were the result of differential thermal contraction of the enclosing host mineral and the included liquid during cooling from a higher temperature of trapping to the temperature of observation (room temperature). Consequently, reheating of such inclusions would lead to disappearance of the bubble and the temperature at which this occurs (homogenization temperature) could serve as an estimate on the temperature of mineral formation. His outstanding talent for observation and precise documentation resulted in five attached plates which represent the first systematic documentation on observed fluid inclusions and which have maintained their validity for petrological interpretations even today.[743]

Experimentally Sorby proved that the most common liquid in fluid inclusions is water. He heated and decrepitated inclusions, collected and condensed the released vapour, cooled it and determined the resulting solids at low temperatures by their shape and their melting point to be ice crystals. Moreover he identified other components released during these experiments as sylvite (KCl) and halite (NaCl). In experiments with artificial fluid inclusions he showed that the expansion coefficients for a variety of solutions on heating were one or two orders of magnitude greater than those of the enclosing host minerals. From these experiments he developed a set of formulae which permitted the calculation of

[735] Brewster, D. 1823. On the existence of a group of movable crystals of carbonate of lime in a fluid cavity of quartz. Edinburgh Philosophical Journal 9:268-70.; *ibid.*, 1823. On the existence of two new fluids in the cavities of minerals, which are immiscible, and which possess remarkable physical properties. Edinburgh Philosophical Journal 9:94-107.

[736] Nichol, W. 1828. Observations on the fluids contained in crystallized minerals. Edinburgh Philosophical Journal 5:94-96.

[737] Dumas, J. 1830. Note sur une variété de sel gemme qui décrépite au contact de l'eau. Annales de Chimie et Physique 43:318-20.

[738] Rose, H. 1839. Über das Knistersalz von Wieliczka. Annalen der Physik und Chemie 48:353-61.

[739] -. 1845. On the existence of crystals with different primitive forms and physical properties in the cavities of minerals; with additional observations on the new fluids in which they occur. Transactions of the Royal Society of Edinburgh 16:11-22.

[740] Bunsen, R. 1851. Über die Prozesse der vulkanischen Gesteinsbildung Islands. Annalen der Physik und Chemie 83:197-272.

[741] Johnson, D. A., ed. 1979. H. C. Sorby centenary issue. Journal of the Geological Society of the Sheffield University 7 (4): 181-93.

[742]
[ Title Needed ]
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[743] Touret, J., 1984. Les inclusions fluides: histoire d'un paradoxe. Bulletin Minéralogiques 107:125-37.

the homogenization temperature for a given inclusion on the basis of the observed filling degree (i. e. the volume fraction of the liquid phase) at room temperature for a variety of compositions.

The formal perfection and the innovative character of Sorby's paper inspired Jacques Touret (1984) to compare it with other masterpieces which marked the beginning of a new technique such as the bible of Johannes Gutenberg or the violins of Antonio Stradivari.[744]

The German scientists Hermann Vogelsang [1838-1874] and Ferdinand Zirkel [1838-1912] were among the first to use the terminology and the techniques of Sorby to carry out further investigations on fluid inclusions in rock-forming minerals, in particular on plutonic and volcanic rocks.[745] Zirkel furthermore heated fluid inclusions and examined the vapour with spectroscopical methods.[746]

The first primitive heating stage was constructed by John Arthur Phillips [1822-1887], in 1875, who used a paraffin bath for this purpose.[747] Other scientists working on fluid inclusions at that time were Walter Noel Hartley [1846-1913],[748] and Edward Sang [1805-1890] in England,[749] or George Wesson Hawes [1848-1882][750] and Charles Lee Reese [1862-1940] in the United States of America.[751] In Russia many researchers critically reviewed the articles of their German, English and American colleagues (see, for example, Karpinsky 1880).[752]

Until the end of the 19th century more than 150 papers were published on fluid inclusions. In spite of this fact the turn of the century was characterized by a certain scepticism about the use of fluid inclusions, partly influenced by some critical papers of Phillips (1875)[753] and Zirkel (1873).[754] Nevertheless until 1920 about 50 more articles appeared by well-known researchers like Harry Rosenbusch [1836-1914],[755] Johann Georg Koenigsberger [1874-1946] and Wolf Johannes Müller [1874-1942],[756] and Rudolf Scharizer [1859-1935][757] mainly to test the usage of this method for solving different problems of mineral formation and formation of ore deposits.

1921 marks a turning point in the fluid inclusion research. Some scientists now considered the problems exclusively from the physico-chemical point. The German Richard Nacken (b. 1884) was the first to apply state diagrams of water and carbon

[744] Touret, J., 1984. Les inclusions fluides: histoire d'un paradoxe. Bulletin Minéralogiques 107:125-37.

[745] Vogelsang, H. 1867. Philosophie der Geologie und mikroskopische Gesteinsstudien. Bonn: Cohen und Sohn.; Vogelsang, H., and H. Geissler. 1869. Über die Natur der Flüssigkeitseinschlüsse in gewissen Mineralien. Annalen der Physik und Chemie 137:56-75.; Zirkel, F. 1866. Über die mikroskopische Zusammensetzung und Structur der diesjährigen Laven von Nea-Kammeni bei Santorin. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie 53:769-87.

[746] Zirkel, F. 1870. Mikromineralogische Mitteilungen. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, 1870, 801-32.

[747] Phillips, J. A. 1875. The rocks of the mining district of Cornwall and their relation to metalliferous deposits. Quarterly Journal of the Geological Society of London 31:319-45.

[748] Hartley, W. N. 1877a. Observations on fluid-cavities. Journal of the Chemical Society of London 31 (1): 241-49.; *ibid.*, 1877b. On attraction and repulsion of bubbles by heat. Proceedings of the Royal Society of London 20 (18): 150-52.

[749] Sang, E. 1873. Notice of a singular property exhibited by the fluid enclosed in crystal cavities. Proceedings of the Royal Society of Edinburgh 8:86-88.

[750] Hawes, G. W. 1881. On liquid carbon dioxide in smoky quartz. American Journal of Science 21:209-16.

[751] Reese, C. L. 1898. Petroleum inclusions in quartz crystals. Journal of the American Chemical Society 20:795-97.

[752] Karpinsky, A. P. 1880. On the occurrence of inclusions of liquid carbon dioxide in mineral substances. Gornyi Zhurnal 2 (4-5): 96-117.

[753] Phillips, J. A. 1875. The rocks of the mining district of Cornwall and their relation to metalliferous deposits. Quarterly Journal of the Geological Society of London 31:319-45.

[754] Zirkel, F. 1873. Die mikroskopische Beschaffenheit der Mineralien und Gesteine. Leipzig: Wilhelm Engelmann Verlag.

[755] Rosenbusch, H. 1887. Mikroskopische Physiographic der Mineralien und Gesteine. Bd. 2. Stuttgart: Schweizerbart.

[756] Königsberger, J., and W. J. Müller. 1906. Über die Flüssigkeitseinschlüsse im Quarz alpiner Mineralklüfte. Centralblatt für Mineralogie 1906: 72-77.

[757] Scharizer, R. 1920. Zur Frage der Bildung der Einschlüsse von flüssigem Kohlendioxyd in Mineralien. Centralblatt für Mineralogie, Abt. B., 1920: 143-48.

dioxide.[758] He further showed that only saline fluid inclusions with a vapour bubble can be used as a thermometer, whereas gaseous fluid inclusion mainly composed of carbon dioxide are excellent indicators to determine the pressure during the formation of the host mineral. Nacken thereby systematically used synthetic fluid inclusions for his experiments. Many other scientists added new ideas on the formation and interpretations of fluid inclusions. They emphasized the importance to distinguish between primary and secondary inclusions, proved that some of the older work contained misinterpretations and tried to convince the scientific world of the reliability of microthermometry as a serious method.

## 7.2 Artificial Minerals[759]

**REWORK:** Speculation on how metals and minerals formed within the earth has always existed in history. Aristotle's theory of mineral formation revolved around exhalations inside the earth interacting with physical conditions such as hot or cold to form minerals. Later, it was a popular belief that a mineral seed existed deep in the rock from which the minerals and metals grew. The basic idea of the philosopher's stone came from similar speculation. It was not until the invention of physical chemistry at the end of the eighteenth century that experimenters slowly recognized that minerals and rocks were actually complex chemical compounds that had formed under very different conditions than existed on the surface of the earth. They theorized that the conditions inside the earth that were present when a specific mineral or rock formed could be experimentally duplicated, and through the introduction of the proper chemical elements, artificial minerals might be artificially created.

In the nineteenth century the first attempts were made to create minerals and igneous rocks artificially. The different methods employed were classified by the researchers as follows:

1. Crystallization by fusion (simple fusion without solvents; fusion with solvents but without chemical reactions; fusion involving chemical reactions).
2. Crystallization by sublimation (simple sublimation; chemical reaction between volatile substances; reaction between volatile and non-volatile substances).
3. Crystallization by solution (solution without chemical action; chemical reaction of two liquids; reaction of liquids and solids).

On the whole, the experimental work that began in the nineteenth century has tended to confirm the observations of mineralogists and petrographers in the field.

The English chemist James Hall [1761-1832] appears to be the first to successfully create artificial minerals and rocks. Among the most interesting syntheses were: the laboratory production of marble from limestone (James Hall, 1801).

Hall is remembered chiefly for the experimental work he carried out to counter certain criticisms of James Hutton's *Theory of the Earth*, although he made other important contributions to geology. His first reaction to the *Theory* had been unfavorable, and it was only after numerous conversations with Hutton that he was persuaded to accept most of its fundamental principles. Once convinced, he provided strong support for Hutton, not only by his experiments but also by field observations.

Hall's first experiments were undertaken to refute the claim that if igneous rocks had originated as molten masses injected into overlying strata, they would be found to occur naturally as masses of glass, not as crystalline rocks. This claim was made because earlier experimenters had found that artificially melted basalt and similar rocks, when cooled, formed a glass. Hall had read accounts of René Reaumur's experiments on porcelain; and in a local glass foundry he had noticed that a mass of molten glass which had been allowed to cool slowly had congealed to a stony mass containing some crystals. He conceived the idea that igneous rocks, if they had cooled slowly, as seemed probable under natural conditions, would form crystalline rocks rather than a

[758] Nacken, R. 1921. Welche Folgerungen ergeben sich aus dem Auftreten von Flüssigkeitseinschlüssen in Mineralen? Centralblatt für Mineralogie 1921: 12-20, 35-43.

[759] Groth, *Entwicklungsgeschicte der mineralogischen Wissenschaften*, 1926, p. 226-228.

glass. Not long after Hutton's death in 1797 he carried out a series of experiments to prove this.

Hall melted specimens of intrusive and extrusive basalt ("whinstone and lava") from fifteen British and foreign localities and allowed the fused masses to cool slowly. The cooled melts he obtained were stony masses, sometimes containing obvious crystals; but none, so far as is known, resembled at all closely the rocks from which they had been derived. Some of his cooled melts have been preserved, and subsequent microscopic examination has shown that one of them contained small crystals of feldspar, augite, olivine, and iron ore, minerals characteristic of the rocks used in the experiments. Hall's results were sufficiently convincing to prove that fused basalt does not necessarily cool to a glass; but he had not taken into account the fact that, under natural conditions, igneous rocks take very much longer to cool than the time that he had allowed.

The second criticism dealt with by Hall was the obvious one that if the consolidation of limestones had been effected in the manner Hutton supposed—by the action of subterranean heat—they would have decomposed with loss of carbon dioxide. Hutton had in fact suggested that this would not happen if the limestones were heated under great pressure, such as that which would be exerted by an overlying mass of seawater. Hall proved this experimentally.

The task proved extremely difficult, but Hall showed great determination and remarkable experimental skill in bringing his investigation to a satisfactory conclusion. Between 1798 and 1805 he carried out more than 500 separate experiments. It was a classic case of proceeding by trial and error. No apparatus suitable for his purpose existed, and Hall had to design and construct his own. His method was to insert small weighed amounts of various types of limestone or carbonate of lime into a tubular container. Among many difficulties he encountered, the principal ones were the selection of suitable material for the container (which had to be nonporous and capable of withstanding both high temperature and high pressures) and the devising of an effective method of sealing the container after inserting the carbonate of lime.

Hall used Wedgwood pyrometers to regulate the temperature and related the Wedgwood scale to the melting point of silver. On this basis it seems probable that he attained temperatures in excess of 1000 °C. To estimate the pressures reached, he adapted to his purpose a method devised by Count Rumford to measure the explosive power of gunpowder. He converted his results to a figure significant in relation to Hutton's theory, the highest pressure obtained being equivalent to a column of seawater 2,720 meters in height.

Hall certainly proved that limestone can be heated to high temperatures under high pressure without suffering decomposition. In the most successful of his experiments the loss in weight of the heated limestone was insignificant. It is probable that in some experiments he produced crystalline marble. He also claimed to have fused limestone; recent research suggests that possibly he may have done so, but this is uncertain. It was many years before Hall's experiments were repeated successfully, and his results aroused great interest in Europe. Some of the apparatus he used and the end products of his experiments on basalt and limestone are now in the Geological Museum in London and in the British Museum (Natural History).

In 1848 the German mineralogist Johann Friedrich Ludwig Hausmann [1782-18??] published the results of his investigations into the material that formed on the walls in the furnaces and smoke stacks of various smelters in Germany.[760] He found that a variety of mineral species were sublimated and deposited on the interior of the stacks, and included the following metals, silver, lead, copper, iron, and bismuth, as well as the mineral species galena, sphaerite, cuprite, magnetite, chrysolite, orthoclase, and annabergite.

The production of artificial quartz and orthoclase by the action of pure or slightly carbonated water under high pressure (Senarmont 1851, Daubree and Friedel).

[760] J.F.L. Hausmann., "Beiträge zur metallugischen Krystallkunde," *Abhandlungen des Gesellschaft der Wissenschaften, Göttingen*, **4** (1848-50) and **5** (1851-52).

In his 1852 doctoral dissertation,[761] N.S. Manross working in Wöhler's laboratory at the University of Göttingen showed techniques for artificially forming a variety of minerals including barite, celestite, anhydryite, apatite, pyromorphite, wolframite, scheelite, crococite, wulfenite, and anglesite. Previously, Daubrée obtained microscopic crystals of apatite.[762] Hausmann had observed wulfenite occuring in the walls of the furnace at Bleiberg in Carinthia.[763]

1857: Jakob [Joseph] Schabus in his *Bestimmung der Krystallgestalten in chemischen Laboratorien*[764] describes the various forms of crystals created in the laboratory. Rammelsberg in the 1857 supplemental volume to his *Krystallographishe Chemie* frequently references Schabus' work.

1857: F.A. Gurlt., *Der pyrogenneten künstlichen Mineralien*. 1857.[765]

1859: The production of cassiterite (tinstone) and rutile by the action of water vapour on a chloride or fluoride (Daubree). Already in the beginning of the section about the Zusammenvorkommen of the minerals it was mentioned that A. Daubrée had artificially represented krystallisierten dioxides of tin and titanium. The purpose of these work was the proof that the minerals concerned could have formed in nature from volatile halogen connections, on which their paragenetischen conditions pointed. G.-A. Daubrée., *Etudes Synthetiques de Geologie Experimentale*. Paris, Dunod, 1879.[766]

In 1848 Daubrée was summoned to Strasbourg to take the chair of mineralogy and geology, and there he established an important experimental laboratory for the study of mineralogical and geological processes. The pattern of Daubrée's lifework was now established, and he is remembered for his contributions to the understanding of geochemical processes, the application of engineering principles to an understanding of geological structures and mineralization patterns, and the economic exploitation of ore bodies. The first of these interests resulted in Études et expériences synthétiques . . . (1859) . His interest in experimental geology was reflected in Rapport sur les progrès de la géologie expérimentale (1867), which was followed by his work of most lasting significance, Études synthétiques de géologie expérimentale (1879). Many of the experiments described in the latter are still referred to, but ironically it was his mechanical rather than his chemical experiments that most influenced later work. In particular, the production of joint patterns associated with folding and torsion proved a very valuable stim ulus to the experimental studies of such geologists as Bailey Willis and Ernst and Hans Cloos.

By 1865, the literature on mineral synthesis was substantial enough that a bibliography of the subject was compiled by A. Boué.[767] It provides a chronological list of attempts to create artificial minerals, followed by an alphabetical list of the mineral species made, and a review of how artificial rocks are made.

Durocher did work on the production of metallic sulphides by the action of sulphuretted hydrogen on a chloride.

Around the same time, in the center 19. Century, began of Paris into a set of experimental work, which had, without proceeding from geological considerations, substantially the purpose to represent the connections on chemical way, occurring in nature and thus for the mineral customer and for the chemical Krystallographie it became extraordinarily important particularly that they did not permit to examine itself the substances finding in nature in pure and/or their different polymorphe modifications exact reference of their characteristics. This areas affected in particular innovative: J.J.

[761] N.S. Manross., 1852, 32 p.

[762] G.A. Daubrée., *Comptes Rendus*, **32** (18??), p. 615.

[763] J.F.L. Hausmann., *Ann. Chem. und Pharm.*, **81** (18??), p. 224.

[764] Schabus, Jakob [Joseph]., *Bestimmung der Krystallgestalten in chemischen Laboratorien.*

[765] F.A. Gurlt., *Der pyrogenneten künstlichen Mineralien.* 1857.

[766] G.-A. Daubrée., *Etudes Synthetiques de Geologie Experimentale*. Paris, Dunod, 1879.

[767] A. Boué., "Bibliographie der künstlichen Mineralienerzeugung," *Sitzungsberichte der K. Akademie der Wissenschaften, Wien*, **51** (1865), Abtheil I, p. 7-73. [*Cf.* Margerie, 1896, no. 389.]

Ebelmen (1814-1852), who the mechanisms the porcelain factory in Sèvres for its work use could.

1851: H.H. De Sénarmont [1808-1862] In "Expériences sur la production artificielle de polychromisme dans les substances cristallisées" (1851), Sénarmont was the first to describe the production of artificial pleochroism in strontium nitrate pentahydrate, which had been prepared by saturating the substance with ammoniacal logwood extract and other organic dyestuffs. He also reported on less successful experiments involving rock candy (sugar), Rochelle salt, potassium nitrate, and sodium nitrate. The syntheses that Sénarmont carried out in the years 1849-1851 are recounted in "Expériences sur la formation des minéraux par la voie humide dans les gîtes métallifères concrétionnées" (1851) and are an essential contribution to the understanding of mineral formation. Since CO2, H2S, alkali salts, sulfides, and carbonates predominate in thermal springs, he assumed that the formation of ore veins from these components would necessarily occur at elevated temperatures and pressures. Thus he placed those components that he wished to have interact in sealed glass tubes, which were inserted into a sealed pipe filled with water. The apparatus was then embedded in coal dust and heated in the gas ovens of the steel mills at Ivry-sur-Seine. Through either double decomposition of a soluble salt with Na2CO3 or CaCO3, or precipitation of a soluble salt using alkali carbonate in a supersaturated CO2 solution, Senarmont produced magnesite, siderite, rhodochrosite, cobalt carbonate, nickel carbonate, smithsonite, and malachite, as well as barite, fluorite, and quartz in crystalline form.

Senarmont also synthesized pure silver, copper, arsenic, and hematite. From metallic salts and alkali sulfides he obtained mostly amorphous sulfides-including marcasite, pyrite, manganese sul-fide, hauerite, NiS, CO3S4, sphalerite, galena, and chalcopyrite; and he obtained realgar, orpiment, stibnite, bismuthinite, arsenopyrite, proustite, and pyrargyrite in crystalline form. He was similarly successful in crystallizing PbS and ZnS in a supersaturated H2S solution and in obtaining pyrite and chalcopyrite in the form of a granulated powder with metallic luster. If he wished to avoid an immediate reaction, he inserted into the glass tube a thin ampul containing a salt and a gas bubble. When heat was applied the gas bubble burst the ampul. Altogether Senarmont succeeded in synthesizing twenty-nine vein minerals from the alkali sulfides and carbonates commonly found in thermal springs with metallic salts. In these syntheses the temperature rarely exceeded 350° C. He gave an exact crystallographic description of all the compounds he was able to crystallize. In addition, he described the effect of the solutions employed on the glass tubes, the flaking off of pieces of glass from the tubes, and the danger of explosion involved in the use of sealed tubes (bombs).

The famous chemist H.E. Sainte Claire Sainte-Claire-Deville (1818-1881) and in the section about the krystallographische study of the minerals already appreciative. Deville was one of the most prolific and versatile chemists of the nineteenth century, making major contributions in most areas of his science. Deville was essentially an experimentalist and had little interest in chemical theory. He worked out a process for producing pure aluminum by reducing its salts with sodium. Deville's methods made both metals readily available and drastically reduced their cost, but he himself did not take much part in their later industrial development. He used the sodium obtained by his method for the preparation of such elements as silicon, boron, and titanium. His investigations of the metallurgy of platinum led to honors from the Russian government. In many of his studies, such as those on the artificial production of natural minerals, Deville employed very high temperatures and became a recognized authority on the use of this technique.

Henri Jules Debray [1827-1888]. He undertook his first scientific work in collaboration with St. Claire Deville, a professor at the École Normale. Their first experiments were in the use of an oxyhydrogen blowpipe to melt platinum. They were commissioned by the Russian government to investigate the applicability of platinum-indium alloys to coinage

and ascertained that these alloys resist corrosion even better than platinum does. At their suggestion the standard meter in Paris was made, under their supervision, from an alloy composed of 90 percent platinum and 10 percent iridium. In further publications Debray reported on investigations of the compounds of tungsten, arsenic, and antimony; on the properties of rhodium; and on the compounds in the platinum metals family and methods of separating them.

1875: C.W.C. Fuchs, *Die Künstlich Dargestellten Mineralien.* Haarlem, 1875.[768]

Paul Gabriel Hautefeuille [1836-1902], who into the Sorbonne particularly the mineral synthesis dedicated a laboratory furnished, and a number of younger researchers. That of orthoclase, albite, quartz, emerald and zircon, by chemical reaction in the presence of mineralizers. Influenced in his chemical studies by Deville's thermochemical approach, Hautefeuille was a member of that group at the Ecole Normale Supérieure which included Henri Debray, L. J. Troost, Alfred Ditte, and F. Isambert. Hautefeuille's best-known studies were his reproductions of numerous crystallized minerals by utilizing mineral catalysts and varied temperature conditions; he carried on this research at a time when the generality of polymorphism among crystals was not fully realized. In his doctoral thesis, for example, he established that three different types of titanium dioxide—the rutile, octahedrite, and brookite crystals —could each be prepared in the laboratory from the amorphous dioxide; he also demonstrated the temperature dependence of two of the crystalline forms of silica—quartz and tridymite—and successfully produced a variety of alkaline feldspars and beryls, including the emerald. In his experiments Haute-feuille employed catalysts readily available under natural conditions, and his work confirmed the views of the French school of lithology dating from Élie de Beaumont.

1882: Fouqué and Michel-Levy's elegant experiments on the artificial production of igneous rocks (1878-1881) helped to solve a number of outstanding problems. In particular, they helped to prove the impossibility of synthesizing granitic rocks by igneous fusion alone. In addition here those geologists, who were occupied with it, belong the minerals arising in the Eruptivgesteinen and to their mixtures, thus those rocks to explain under possible approximation to conditions of their education in nature and with similar petrographic characteristics; there is this above all F. Fouqué (1828-1904) and its pupils lind coworker A. Michel-Lévy (1844 to 1911), who its work inVdem mineralogical laboratory of the École standard. sup. implemented. There is also an extensive collection of preparations of the French Mineralsynthetiker, while the most complete is set up in the mineralogical collection of the École of the mines. The first systematically arranged discussion of the all artificial representations of minerals, implemented up to then, contains the work ven of F. Fouqué and Michel Michel-Lévy, *Synthèse Minéraux et la Roches* (Paris 1882).[769]

Fouqué in collaboration with Michel-Lévy, he successfully synthesized a large number of igneous rocks in an attempt to determine the conditions necessary for the production of their mineralogical constituents. From 1878 to 1882, Fouqué and Michel-Lévy worked continuously on the artificial synthesis of igneous rocks, primarily to determine the conditions surrounding their origins. They were successful in producing the majority of volcanic rocks with the identical mineralogical composition and structural peculiarities found in nature. Their work verified the importance of the rate of cooling on the extent of crystallization and the sizes of grain, and demonstrated that rocks of distinctly different mineralogical composition would be formed from the same magma, depending on the conditions of crystallization.

From 1878 to 1882 Michel-Lévy and Fouqué worked to synthesize igneous rocks artificially, believing that if they could determine the peculiar conditions surrounding

[768] C.W.C. Fuchs., *Die Künstlich Dargestellten Mineralien.* Haarlem, 1875.

[769] F.A. Fouqué and M. Lévy., *Synthèse des Minéraux et des Roches.* Paris, Masson, 1882.

the rocks' genesis, they might arrive at important geological conclusions. Despite the meager equipment of the laboratory at the Collège de France in which they carried out their experiments, they produced rocks having the mineralogical composition and structure identical with most of the volcanic rocks found in nature. They published jointly twenty-two articles and a book, Synthèse des minéraux et des roches (1882), which incorporated the results of their work. Their most important conclusions were that the degree of crystallinity depended largely upon the rate of cooling and that rocks of distinctly different mineralogical compositions would be formed from the same magma, depending upon the conditions of crystallization. Their failure to reproduce the trachytes and rhyolites demonstrated that in order to obtain the characteristic elements of these rocks, the presence of mineralizers was necessary to lessen the viscosity of the magma and to allow crystallization.

1884: Soon thereafter (1884) the careful composition of L.Z. Bourgeois followed this in that in an Appendix to the second volume of the *Encyclopédie Chimique* published by Frémy. Apparently, it was reissued separately.[770]

1884: The extensive work of the Norwegian J. H. L. Vogt, which supplied "Studien über Schlacken" (Stockholm 1884) connections krystallisierter in the paper under use of the analyses Äkermans the proof of the occurrence of a row in metallurgical products and which knowledge of the emergence of minerals in dry Schmelzflüssen in the following years importantly extended.

1890: Charles Friedel The role of water as a mineralizer, in the supercritical state and in the presence of alkali salts, which was first demonstrated by Friedel (1890-1891). Charles Friedel, succeeded in producing percylite, cumengeite, and boleite. Famous chemist Charles Friedel (1832-1899), who taught mineralogy and organic chemistry at the University of Paris and was, at the same time, the curator of the mineralogical collections of the School of Mines. He introduced his son, Georges Friedel [????-????], the famous crystallographer to mineral synthesis when he was still in his teens. Together the Friedels first published accounts of a number of syntheses produced in a steel tube lined with platinum, at about 500° C. and under high pressure. Synthetic minerals were prepared by letting group I hydroxides and silicates or salt solutions act on mica. Among nonminerals he obtained tricalcium aluminum hexahydroxytrichloride di-hydrate (1897) and a calcium aluminate (1903), both known for their twinning, and lithium metasilicate (Li2SiO3), which syncrystallizes with beryllium orthosilicate (Be2Si04). With François Grandjean, Georges Friedel went on to synthesized chlorites by attacking pyroxene with alkali solutions (1909). By preparing potassium nepheline (1912) he settled the question of "excess silica" in the nepheline formula.

Georges Friedel's work (1896-1899) established the interstitial nature of zeolitic water, which can be replaced by many liquids and gases in the zeolitic "sponge." He found zeolitic water in compounds other than zeolites.

1890: Cornelius Doelter in 1890 reproduced the zeolites (apophyllitc, okenitc, chabazite, phacolite, heulandite, stilbite, launiontite, thomsonite, analcite, natrolite, scolecite, prehnite). Doelter insisted on the confirmation of all suppositions through experiment. He first devoted himself to synthesis and prepared nepheline and pyroxenes (1884), a sulfide and a sulfosalt (1886), micas (1888), and a zeolite (1890). In this work he improved Charles Frieders pressure vessels and used liquid and solid carbon dioxide to obtain higher pressure. Experiments on remelting and recrystallization carried out after 1883 had shown that minerals other than the original ones could be separated out from the fused mass. For example, Doelter obtained an augite andésite from a fused mass of eclogite. He likewise investigated the remelting of rocks and the influence of mineralizers on the occurrence of rock-forming minerals. His *Allgemeine chemische Mineralogie* (Leipzig, 1890) presented the knowledge he had gained of these matters.

[770] L.Z. Bourgeois., *Reproduction Artificielle des Minéraux.* Paris, Dunod, 1884.

In 1890 Doelter studied the absorption of water by dehydrated zeolites and the solubility of silicates in water. At the same time he demonstrated that in electrolysis, fused basalt concentrates iron at the cathode and that, therefore, fused silicates behave like electrolytes and not like alloys. Since the application of the physical-chemical laws developed for aqueous solutions to silicate fusions was hampered by the lack of reliable constants, Doelter began in 1899 to determine the melting points of important minerals and, in 1901, those of mixtures. In 1901 he ascertained the volume increase of liquid and solidified rock fusions relative to the solid parent rock and found that minerals which are difficult to fuse are also difficult to dissolve and very hard (1902). In 1902 Doelter presented a viscosity series from liquid basalt to viscous granite, recognizing the influence of mineralizers on viscosity and on the lowering of the melting point, as well as their catalytic and chemical activity—e.g., in the formation of mica and of tourmaline. Moreover, he found that magmatic differentiation "is nothing else than the final result of mineral segregation." For melting-point determinations he constructed the crystallization microscope built by C. Reichert with the heating oven of W. C. Heraeus (described in 1904; improved in 1909). In 1904 he was able to confirm the suspected influence of the inoculation of solution-melts with seed crystals.

With his *Physikalisch-chemische Mineralogie* (Leipzig, 1905), Doelter showed himself to be, along with J. H. L. Vogt, the most important cofounder of this new discipline, even though he held that the direct transfer of the results of physical chemistry was not always possible, because in silicate fusions a restoration of equilibrium is impeded by the subcooling and by reduced diffusion resulting from viscosity. The chief advantage that he saw in physical chemistry was that it had set the direction that experimental work should follow.

1891: Etienne Stanislaus Meunier *Les Méthodes de Synthèse en Minéralogie* (1891) is a comprehensive textbook describing all aspects of synthesizing mineral compounds in the laboratory. Meunier describes the accidental creation of minerals as well as giving the scientific rational behind mineral creation. He then provides detailed instructions for creating a large number of mineral species in the laboratory including recipes, apparatus, coloring agents, etc. The entire text is fully referenced to original citations and includes at the conclusion indexes to the names of the various authors and a comprehensive subject listing.

1891: Johan Hermann Lie Vogt [1858-1932] studied the formations of minerals in slags and lavas in 1891. Structural formulae-in analogy with those evolved in organic chemical research-were evolved. R. Schauzer contributed hypothetical graphic formuke for the organization of Orthoclase, Kaolin, Hydrargillite, Pyrophyllite, Talc, Serpentine, Brucite, Enstatite, and Clarke attacked the problem of the zeolites. Vogt in 1894 went on with his interesting inquiries into the genesis of minerals, reproducing-or trying to do so-the formation of ore deposits by differentiation processes in basic magmas. These studies were later published in Vogt's *Die Silikatschmelzlösungen mit besonderer Rücksicht auf die Mineralbildung* (1903-1904).[771]

Vogt was a pioneer in ore geology and in the physical chemistry of silicates as a basis for igneous rock petrology. His work in the latter field began with studies of slag minerals. In a series of papers, the first of which appeared in 1883, he provided the first descriptions of a number of slag minerals: enstatite, wollastonite (pseudo-wollastonite), fay alite, monticellite varieties, åkermannite, oldhamite, manganblende (alaban-dite), troilite, and sphalerite. Vogt soon began using the crystallization of slags as a model for silicate crystallization in igneous rocks, as shown by the title of his papers of 1888-1890: "Beiträge zur Kenntnis der Gesetze der Mineralbildung in Schmelzmassen und in den neovulkanischen Ergussgesteinen." Inspired by his mineralogical studies of slags, he generalized his studies of ores and silicate rocks in "Die Silikatschmelzlösungen" (2 pts., 1902), a pioneer paper in

[771] J.H.L. Vogt., *Die Silikatschmelzlösungen mit besonderer Rücksicht auf die Mineralbildung.* 1903-04.

which the crystallization relations of the different minerals and their dependence upon eutectic relations are considered. The lowering of melting points in melts with several components and the importance of eutectic compositions in binary series are discussed. The general relationships are applied to natural silicate melts and specifically to the eutectic relation between quartz and feldspars in igneous rocks. Bearing still more directly on natural relationships is "Physikalisch-chemische Gesetze der Kristallizationsfolge in Eruptiv-Ge-steinen" (1905), in which the crystallization within the ternary feldspar system orthoclase-albite-anorthite and the granite system quartz-orthoclase-al-bite is discussed. Not all of Vogt's main conclusions have proved correct, but he applied the principles of physical chemistry to natural silicate systems more intensely than anyone else of his generation and therefore is often called the father of modern physicochemical petrology.

The progress made in the subject of mineral synthesis has been remarkably rapid in the last two decades, and the success of the French chemists in this line has been particularly marked. The excellent books of Fouqué and Levy (1882) and of Bourgeois (1884), which gave a full summary of what had been accomplished in the way of forming artificial minerals, are now followed by a volume by another active worker in the same field, Étienne Stanislaus Meunier [1843-1925] . In 1891 he published his *Les Méthodes de Synthèse en Minéralogie*[772] that occupies a place of its own, for it is devoted particularly to an explanation of the methods used and general principles involved. The first part discusses the contemporaneous formation of minerals in nature; and a second part is given to the cases of accidental synthesis, furnace products, etc. The third and most important division describes the method of synthesis proper; first by the dry way involving simple crystallization by molecular change, by igneous fusion and by the intervention of a mineralizer; then simple decomposition; chemical union; precipitation and finally, double decomposition. The methods of synthesis in the wet way are also described with similar system and thoroughness as also those where the method is mixed. This summary will give an idea of the wide range of topics here presented, but the volume calls for the close study that it fully merits.

1894: Bruno Doss in 1894 artificially prepared Anatase and Rutile, by saturation of a bead of microcosmic salt with titanium oxide.

1896: About this time (1896) L. Michel made artificial Powellite.

1896: One to close to conclusions 19 Century continued representation of this area gave *Chemische Mineralogie* (Leipzig 1896) of Reinhard Brauns.

1898: Other experimental studies have yielded important clues to the origin of certain microstructures observed in metallic ores. In the same direction J. Morocewicz (1898), and A. Lagoiro were active in Warsaw.

In 1899 G. Bodländer treated the now important question of "solid solutions," which Van't Hoff first promulgated. This is a profound study having to do with the intermixtures-solution so-called-of solids in each other.

Mineral Synthesis had been greatly advanced, Daubree, Doelter, Levy, Fouque and others contributed to this subject and elaborate speculations upon the constitution of minerals filled the journals.

Muthmann and Kuntze, R. Brauns, Ben Saude, contributed observations upon the optical anomalies of metric crystals, in which emerged the idea that in the process of crystallization, for an instant, upon hardening not only a contraction of the mass, as in colloidal bodies, occurs, but the form of the crystal has an influence upon this contraction which gives rise to various and contrasted effects, according to the nature of the surrounding mass, according to pressure, to temperature, and the concentration of the solution and always similar effects under similar conditions.

1910: C. Doelter are in detail treated with the individual minerals the syntheses the same drew up extensive hand beech of mineral chemistry. The synthetic studies of

[772] Étienne Stanislaus Meunier., *Les Méthodes de Synthèse en Minéralogie*. Paris, 1891. 359 p.

Doelter were always a subject of perennial interest to that industrious investigator, and they were continued with interesting results. He found upon melting potashmica, that recrystallization yielded leucite and nephelite, lithia-mica also produced leucite and nephelite ; zinnwaldite, leucite ; magnesia, mica, augite, spinel, chrvsolite, meionite, orthoclase(?) ; clinochlore, spinel, olivine, augite ; tourmaline, olivine, spinel ; axinite, augite datolite, olivine, anorthite, pyroxene( ?) ; epidote, augite and anorthite, and, with mixtures of fluoride of sodium and calcium, anorthite and meionite. Zoisite and manganese chloride yielded manganese garnet ; garnet itself with a fluoride, biotite, or with less fluoride, anorthite, meionite, augite. Doelter further experimented upon the syntheses of hornblende, wernerite, acmite, and came to the conclusion that through the influence of fluorides, chlorides, and through the influence of varying temperatures a fixed mixture gave most diverse results.

1913: Norman Levi Bowen [1887-1956] have done decisive work on the reproduction of magmatic minerals by the 'dry path'. In preparing his doctoral dissertation on a phase-equilibrium study of the nepheline-carnegieite-anorthite system, Bowen followed the work of the Norwegian J. H. L. Vogt, who had made petrological analyses using physical chemistry. He worked under the direction of A. L. Day of the Geophysical Laboratory and was also influenced by early association with R. A. Daly.

Bowen published critical phase diagrams for the study of the major igneous rocks: the plagioclase system in 1913, the MgO-SiO2 system and the ternary system diopside-forsterite-silica in 1914, and, with colleagues, another twenty-one phase diagrams; the last appeared almost coincidentally with his death. From the beginning, his principal concern was the differentiation of igneous rocks. In 1927 he wrote: ". . . rock series can not be partitioned off into such divisions as gabbro, diorite, etc., each having a eutectic of its own. All of these belong to a single crystallization series, to a single polycomponent system, which is dominated by reaction series."

Silicate phase-equilibria studies, in particular his own plagioclase diagram, formed the bases on which Bowen published his carefully reasoned theory of the ...

A practical textbook describing the various methods and techniques to create artifical minerals was published by E. Dittler in 1915 as the *Mineralsynthetisches Praktikum*.[773]

1920: In a prize winning essay published (Presschrift) in Leipzig W. Eitel appeared a critical and treatment of the syntheses of the feldspar representatives particularly supplemented by own attempts important for the petrographic research communicated, to a group of silicates, which sets particularly large difficulties to the reproduction against.

### Precious Stones

A subset of the manufacturing of artificial minerals that had besides interesting theoretical concerns but also important financial associations, was the creation of gem crystals. Because of their importance and value as ornamental stones, rubies, sapphires, diamonds, emeralds, and others have been the subject of intensive investigations.

1728: Charles-François De Cisternai Du Fay wrote on the the coloring of artificial gems ( 1728)–(DSB).[774]

By investigating the reaction at high temperatures of volatile fluorides on oxygen compounds, H. Saint Claire Deville [1818-1881] and his assistant obtained in 1858 crystals up to two centimeter of white and green corundum, ruby, sapphire, zircon, chrysoberyl, and spinel. To obtain the red corundum or ruby, they added trace amounts of fluoride of chromium to the mixture. They observed that if too much chromium was added, the corundum developed a fine green color. They also produced the aluminum silicate mineral staurolite by either decomposing fluoride of aluminum by silica or fluoride of silica by aluminum.

Kunz ...[775]

[773] E. Dittler., *Mineralsynthetisches Praktikum*. 1915.

[774] ????? C.-F. Du Fay., "Observations sur quelques expériences de l'aimant," 1728, p. 355-369.

[775] George F. Kunz., "On the new artificial rubies. Illustrated with specimens and microscopical preparations," *Transactions of the New York Academy Sciences*, **6** (1886), 4-11.

The synthesis of rubies, 1877-1891. E. Frémy (1891) published his laborious work in the artificial production of the ruby.[776] It was in 1877 that he and M. Feil first achieved success; at first the ruby made was in sheets, lamellar and friable, but of no practical use. The color was obtained from bichromate of potash. As the alumina should be very pure, ammonia alum was calcined to obtain it: the alumina was mixed with K2Co3 and this mixture again with fluoride of beryllium and potassium bichromate. Prolonged calcination of the mixture at 1500° C. with circulation of moist air followed. The moisture disengages hydrofluoric acid, this appears to effect the isolation of the alumina which has combined with the alkali or the earth, and crystallization succeeds. From research on the setting of hydraulic cement, Frémy proceeded to the synthesis of rubies by heating alumina with potassium chromate and barium fluoride.

Verneuil

Diamonds ...[777]

Wilbert Goodchild., *Precious stones, by W. Goodchild ... With a chapter on artificial stones, by Robert Dykes.* London, A. Constable and co. ltd., 1908. x, 309 p. illus.[778]

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## 8.0 Crystallography[783]

[776] Frémy, *La Synthèse Du Rubis*, 1891.

[777] Boutan, *Diamant. Encyclopédie chimique de Frémy*, Band II, e. Teil, 1885.

[778] Goodchild, Wilbert. *Precious stones, by W. Goodchild ... With a chapter on artificial stones, by Robert Dykes.* London, A. Constable and co. ltd., 1908. x, 309 p. illus.

[779] Boyer, J., *La synthèse des pierres précieuses.* Paris, Gauthier-Villars 1909. 30, [2] p. illus., plates. German translation, *ibid.*, *Die synthetischen Edelsteine, ihre Geschichte, Herstellung und Eigenschaften.* Berlin, M. Krayn, 1910. 57 p. ill., tables, diagrs. [On artificial precious stones.]

[780] Heaton, N., "The production and identification of artificial precious stones," *Smithsonian Institution. Annual Report, 1911.* Washington, 1912, p. 217-34.

[781] Krauss, F., *Synthetische Edelsteine.* Berlin, Georg Stilke, 1929. 134 p., illus. [Bibliography, p. 116-128.]

[782] Menditti, I., "La collezione dei cristalli artificiali del Real museo mineralogico in Napoli," *Museologia scientifica*, **15** (1998), no. 1, 21-31.

[783] Other historical information may be found in: M. Betz., "One century of protein crystallography: the phycobiliproteins," *Biological chemistry*, **378** (1997), no. 3-4, p. 167-176. • John G. Burke., *Origins of the science of crystals.* Berkeley and Los Angeles, University of California Press, 1966. [8], 198 p., illus., index. [A detailed history of crystallography.] • H. Deas., "Crystallography and crystallographers in early 19th century England," *Centaurus*, **6** (1959), p. 129-148. • V.V. Dolivo-Dobrovolsky., "Évolution de la cristallographie et les problèmes à résoudre," *Zapisky, Inst. Mines, Leningrad, Annal*, **8** (1934), p. 160-169. [History of crystallography, from the aspect of industrial applications.] • E. Fabian., *Die Entdeckung der Kristalle: der historische Weg der Kristallforschung zur Wissenschaft.* Leipzig, Deutscher Verlag für Grundstoffindustrie, 1986. 193 p., illus., portraits. [History of crystallography; ISBN: 3342001089] • Paul Groth., *Entwicklungsgeschichte der mineralogischen Wissenschaften.* Berlin, Julius Springer, 1926. [4], 262 p., index. • J. Lima-de-Faria, ed., *Historical atlas of crystallography.* New York, Elsevier, 1990. 156 p., illus., biblio., index. [Contains much valuable historical material on crystallography.] • C.M. Marx., *Geschichte der Crystallkunde.* Carlsruhe und Baden, D.R. Marx, 1825. xiv, [2], 313, [3] p., 10 plates. [Reprinted, Wiesbaden, M. Sändig, 1970. An early history of crystallography.] • Hélène Metzger., *La genèse de la science des cristaux.* Paris, 1918. 249 p., index. [Excellent history of crystallography, with emphasis on the French contribution.] • I.I. Shafranovskii., Историиа кристаллографии в России [Istoriia kristallografii v Rossii]. Leningrad, Izd-vo Akademii nauk SSSR [Leningradskoe otd-nie], 1962. 413 p., illus. [History of crystallography in Russia] • *ibid.*, Историиа кристаллографии с древнеиших времен до начала 19. столетииа [Istoriia kristallografii s drevneishikh vremen do nachala 19. stoletiia]. Leningrad, Nauka, Leningrrad otd-nie, 1978. 295 p., illus. [General history of crystallography in the 19th century.] • *ibid.*, Историиа кристаллографии ШИШ век [Istoriia kristallografii XIX vek]. Leningrad, "Nauka," Leningradskoe otd-nie, 1980. 323 p., illus., portraits. [History of crystallography in the 19th century. A bibliogaphy of works consulted is given on pages 306-316.] • H. Tertsch., *Das Geheimnis der Kristallwelt. Roman einer Wissenschaft.* Mit 12 Tafeln und 48 Abbildungen. Wien, Gerlach & Wiedling, 1947. 391 p., 12 plates. [History of mineralogy and crystallography.]

The word *crystal* is derived from the Greek word κρυσταλλος, meaning clear ice, mirroring the long held belief that rock crystal, transparent quartz, was permanently frozen water. The Latin *crystallus* is derived from this and describes any geometrically shaped gemstone. The term crystal was extended in the 17th century to include all regularly shaped chemical salts, and subsequently to all natural geometrically shaped objects. The study of the crystallized forms and properties of substances is known as crystallography. It is a science that in its earliest period developed directly from mineral studies, but which since the discovery of X-ray diffraction has grown into a complete discipline separate but still interlinked with its original partner. Due to their inorganic nature most minerals are inherently crystalline in nature and objects of study in crystallography.

## 8.1 Geometrical Crystallography[784]

**REWORK:** During the 16th century studies dealing with crystals were mainly connected with books about minerals and mining; however, some important contributions appeared in which morphological aspects of crystals were considered. At the beginning of the century books on mining, like the German *Bergbüchlein*, referred to the shapes of minerals and their practical applications. In 1540 the Italian Vannoccio Biringuccio [1480-1539] published a book, *De la Pirotechnia*, which is a practical description of the techniques of smelting and refining ores and metals, and contains several references to the perfect shapes of some minerals, in particular pyrite cubes and galena cleavages.

Later, the book by Gerogius Agricola [1494-1555], *De Natura Fossilium* (1546), considered the first textbook of mineralogy, contains a classification of minerals founded on physical properties such as color, weight, transparency, lustre, taste, odor, shape, and texture. In this book, which attributes the so-called powers of minerals to their natural properties and not to supernatural design, there is also commentary by Agricola on the geometrical shape of minerals and emphasized its importance as a distinguishing characteristic.

In his book *De Subtilitate* of 1550, the Italian polymath Girolamo Cardano [1501-1576] tried, without much success, to show that the hexagonal form of quartz was created by the close packing of spherical particles. Cardano wondered about the six-sided forms of quartz (crystallus), suggesting that it might have formed, as did the hexagonal form of the bee's cell, from the surrounding and reciprocal pressures of spheres. But he abandoned this physical explanation, instead assuming some internal force which expressed itself in the length, the breadth, and the depth of the crystal gave rise to the six sides of quartz. This was a view much ridiculed by his opponent, Julius Cäsar Scaliger [1484-1558].[785] Cardano also wrote on the nature and forms of primarily gem minerals. Although he was primarily concerned with their color, he clearly is aware of their crystalline individuality.[786]

Christoph Entzelt (*Latin*, Encelius) [1517-1586] in his *De Re Metallica* (1551) published his observations upon the minerals of the earth, which he had seen.[787] He notes the regularity and persistency of crystals, and expresses his admiration for nature in the depths of the earth that have such power of geometry to create these crystallized masses, where he too says, he as seen figures of little fishes, and the outline of lions and wolfs.

There appeared in 1556 Agricola's most renowned and influential work, *De Re Metallica*, which is mainly concerned with mining techniques.[788] About minerals, he brought into notice, their relation, color, taste, odor, luster, hardness, transparency, density, and

[784] Other historical information may be found in: M. Senechal., "Brief history of geometrical crystallography" (pp. 43-60), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

[785] J.C. Scaliger., *Exotericarum Exercitationum*. Lutetiae, 1557. [4], 476, [31]$\ell$., illus.

[786] G. Cardano., *Somniorum Synesiorum ... De Gemmis et Coloribus Liber*. Basil, 1562. 2 parts. [42], [2] blank, 278 p.; [36], 413, [1] p.

[787] C. Entzelt., *De Re Metallica*. Francofurti, 1551. [16], 271, [1] p., 5 woodcuts.

[788] G. Agricola., *De Re Metallica*. Basilae, 1556. [12], 538 (i.e., 502), [74] p., numerous woodcut illus.

form. Agricola observed the variety of crystalline forms of minerals, how many possessed angles, some had triangular faces, others were cubic like pyrite, while the modifying secondary faces around the terminal pyramids of quartz excited his wonder. He theorized that minerals, especially crystals, had been formed from a pure liquid solution.

Crystallographical studies received an important advance when the German goldsmith and jeweller, Wentzel Jamitzer [1508-1586] prepared 140 models of geometrical forms, in which the original simple forms were abundantly modified and then grouped in composite multiples, so that the resultant polyhedrons suggest twinning and trilling of the forms. He published the results of his study in the *Perspectiva Corporum Regularium* (1568).[789]

The book of Conrad Gesner [1516-1565], *De Rerum Fossilium, Lapidum et Gemmarum*, published in 1565, used a classification of 'fossils' based on two main characteristics, their shapes and names.[790] His first class for example, *Geometrical Forms*, whose forms are based upon, or have some relation to, the geometrical conception of points, lines or angles, includes all transparent or translucent minerals, spherical concretions, and forms that display distinct angles, such as pyrite and quartz. Gesner also pointed out irregularities in the angles and faces of quartz.

At the end of the century Bernard Palissy [c1510-1590] wrote an important book, *Discours Admirables* (1580), in which he attaches importance to the geometrical forms of crystals, observing that all are triangular, quadrangular or pentagonal.[791] He also considered the process of crystallization from solution.

Superstitions and mystical properties were reflected in the various writings of Johann Baptista van Helmont [1577-1644], which involved fabulous and metaphysical explanations, the crude substitute for more radical knowledge, which was then unattainable. Even so, he was the first to speculated correctly on the composition of complex chemical compounds, by reducing them to simple bodies. He utilized quantitative procedures in his studies, developing techniques to study gas formation from fermentation, the evaporation of water, and introduced for the first time the term "gas," and defined its role in different chemical processes. He rejected the old notion that said crystal was water that had undergone extremely cold freezing, saying it was opposed to the essence of life that one thing should pass into another by an exterior influence, viz., snow by cold.

Theophrastus Paracelsus [1493-1541] connected the metals and minerals with the influences of the seven planets and neighboring stars. These metals and minerals had been ejected from these distant bodies and fallen on the earth, but the quartzes, beryls and citrine had been "coagulated" from water contained in the "snow stars," and come to earth with the snow and frost.[792]

The *De Metallicis Libri* authored by Andreas Caesalpinus [1519-1603] and published in 1596, contains information that attempts to reveal the secret of crystallization.[793] He discussed the first artificially prepared alum, saltpeter and sugar crystals, and said of quartz, which because of its universality and perfect crystallization challenged the senses. It has been formed from the purest substance, and so in its six-sided prism very nearly approachs the shape of the circle, which might be regarded as the perfection of form. He imagined the terminal pyramid of quartz was created by deficiency of material for the continuation of the prismatic faces, and that it was more clear and less contaminated than the rest of the crystal, in which, as it were, the dregs of the solution settled.

### 8.1.1 Seventeenth Century

[789] W. Jamitzer., *Perspectiva Corporum Regularium*. Nürnburg, 1568. [8] p., [49] leaves of plates.

[790] C. Gesner., *De Rerum Fossilium, Lapidum et Gemmarum*. Tiguri, 1565. Aa-Cc$^8$ Dd-Yy$^8$ (M8 and i8 blank).

[791] B. Palissy., *Discours Admirables*. Paris, 1580. [16], 361, [23] p.

[792] T. Paracelsus., *Ettliche Tractat Philippi Theophrasti Paracelsi ... von naturlichen Dingen*. Strassburg, 1570. [16], 532 p.

[793] A. Caesalpinus., *De Metallicis Libri*. Romae, 1596. [16], 222, [2] p.

**REWORK:** In the 17th century began to appear the first careful study of crystals. The distinguished Anselmus Boetius de Boodt [c1550-1632] wrote in 1609 in his *Gemmarum et Lapidum Historia* (History of Gems and Stones) that the most influential principle in minerals was a lapidifying power, or a force to form stone. Material separated from solution through withdrawal of heat was drawn into angular shapes, and stones which increase through growth, as crystals, possess a force not dissimilar to that of plants, whereby they are formed. Boodt believed the six sided form of quartz unexplainable, but formed by such causes similar to those that give peculiar shaped leaves and flowers to plants.

Typical of the mediaeval views of the conception of natural world were expressed by Petrus Arlensis (or Peter von Arles) [1580-1637?] when he designed a connection between the seven metals, the seven precious stones, and the seven planets.[794] On the form of quartz he speculats: "When the earthy and supernatural matter separated itself from water, it (the matter) struggles in every part to consolidate itself, and lines (radii), as if drawn from some central point, appear to shoot outward toward the circumference. But, as they (the lines) meet opposing lines, they cannot complete a circle, but only (through peripheral impact) form a six-sided figure." He further asserts that the moon symbolized both silver and quartz.

Johannes Kepler [1571-1630] wrote his *Strena Seu de Nive Sexangula* in 1611, as a New Year's gift to a friend.[795] In it he tries to discover a reason that the shape of snow flakes is always six sided. He speculates that the crystals have an internal structure of minute spherical particles that are densely packed in a symmetrical way. Kepler also contributed to the philosophical discussion of crystallography when he took five geometrical solids and evolved from them a series of forms, related and interdependent, of which many are exactly reproduced in nature.[796]

An important observation to the future of crystallography was when Willebrord Snel (*Latinized*, Snellius) [1580-1626] discovered, but did not publish, about 1621 the law of refraction of light when it transversed a liquid; his discovery has only come down to us through its mention in a later book by Vossius, *De Lucis Natura et Proprietate* (1662). Descartes rediscoved this same law, which he presents in his work *Les Météores* (1637) that was published with the *Discours de la Méthode*.

In 1658 Pierre Gassendi [1592-1655] published a book *De Rebus Terrenis Inanimis* that contains a chapter 'De lapidibus ac Metallis', in which he speculates that crystals are built of discrete particles arranged in a regular way, their polyhedral form, therefore, being a direct result of this process.

The German Jesuit polymath Athanasius Kircher [1601-1680] connected the geometric shapes of the precious stones to the action of the special emitting forces.[797] Like so many of his prdecessors, he attacked anew the persistant problem of crystalline form, and fixed his gaze on the enigmatic six-sided, pyramid terminated quartz. He declares that its particular form is derived from peculiar endowments of the salt composing it, and that in all salts a force caused their particles to build outward from a center along four, five or six lines, and so polyhedral shapes of four, five or six sides were created. The spaces between the lines were filled up by inrushing particles compelled there by a certain magnetic impulse.

In 1665 the the famous *Micrographia* of Robert Hooke [1635-1703] was published. It contains descriptions and observations made by the author through the microscope of many materials, mainly biological, but also of some crystals. Hooke shows the regularity of angle between corresponding faces to be independent of the infinite variety in the sizes of crystal faces, which he explains by the corpuscular hypothesis. He also attempts an explanation of the flat shape of crystal faces by the closest

[794] P. Arlensis., *Sympathia Septem Metallorum ac Septem Selectorum Lapidum Ad Planetas*. It is appended at the end of: Camillo Leonardi., *Speculum Lapidum*. Paris, 1610. [44], 244, [4], 245-499, [36] p., illus., 2 ports.

[795] J. Kepler., *Strena Seu de Nive Sexangula*. Francofurti ad Monvem, 1611. 24 p., 3 woodcut illus.

[796] J. Kepler., *Mysterium Cosmographicum*. 1595.

[797] A. Kircher., . 1665.

packing of spherical particles. He still uses the term 'crystal' for quartz and the the description 'angular bodies' for the other forms of crystals.

In Holland Antonio van Leeuwenhoek [1632-1723] published several memoirs on microscopic observations and in particular on crystal growth (1685); however, his main book, *Arcana Natura Detecta*, which collects together most of his papers, was not published until 1695. He made many valuable obseravations on gypsum including angular measurements of it rhomboic plate. Using a microscope of his own design, Leeuwenhoek saw the increase in size of the needle-shaped small crystals as a drop of solution that contained dissolved gypsum evaporated. He also reports that the angles of the small crystals remain constant as they form.

One of the first important experimental discoveries in crystallography was made in 1669 when the double refraction of light by crystals of Iceland spar (calcite) was reported by Erasmus Bartholin [1625-1698].[798] A distinguished mathematician, he made a series of experiments with calcite, measuring the angles of the mineral's cleavages, which he found them to be constant, even in the smallest fragments, dissolved specimens in various acids, examined its colors, and with astonishment recorded calcite's power of producing duplicate images (double refraction).

Also in 1669 Nicolaus Steno [1638-1686] reported his discovery the constancy of interfacial angles in quartz crystals in his *De Solido Intra Soldum Naturaliter Contento Dissertationis Prodromus*.[799] This is the founding principle in crystallography that laid the basis of the science upon a fixed law and brought into scientific unity a series of apparently disparent information about minerals. The general form of the law, that all mineral crystals have constant interfacial angles would not be stated for more than a century.

Steno also expressed the idea that crystals were created by the accumulation of very small particles. He insisted upon the formation of crystals from the outside by the addition of material derived from a fluid in which they might be immersed, not from some vegetative process that grew them from the inside. He noticed the unequal enlargement of crystals, their obliquity, and in the case of quartz explained the striated prismatic faces were due to the oscillation of the terminal (pyramidal) faces with the side (prismatic) faces.

Double refraction was theoretically examined by Christiaan Huygens [1629-1695], who observed the phenomena in calcite, and wrote an exhaustive treatment of the subject that left little of subsequent speculation.[800] He also is credited with detecting double refraction in quartz, only the second mineral discovered to exhibit the property. He anticipated some modern molecular theories, in his suggestion that calcite was made up of minute ellipsoids, arranged in such a way as to form rhombohedral pyramids, and that the points of their consecutive contact along certain planes, parallel to the rhombohedral faces, formed surfaces of easy cleavage.

Isaac Newton [1642-1727] was also intrigued by the double refraction exhibited by calcite. Indeed, it was from his experiments with how light interacted with the mineral that led him to advance his theory of the four-sided nature of light and to oppose the theory of wave-motion. Newton also calculated the thickness of the thinnest plates of mica and gypsum.

The English chemist Robert Boyle [1627-1691] about mid-century, in his book *The Sceptical Chymist* (1661) used the word *crystal* in a general sense, not restricting its meaning to rock crystal (quartz). In 1672 he published the book, *An Essay about the Origin and Virtues of Gems*, where he takes notice of the constant shape of each mineral species, but not to the constancy of their interfacial angles.[801] Like Steno, he also believed that crystals grew from fluid solution by the

[798] E. Bartholin., *Experimenta Crystalli Islandici Disdiaclastici*. Hafniae, 1669. [4], 60 p., diagrams.

[799] N. Steno., *De Solido Intra Soldum Naturaliter Contento Dissertationis Prodromus*. Florentiae, 1669. [2], 78, [2] p., one folding plate.

[800] C. Huygens., *Traité de la Lumière*. Lugduni Batavorum, 1690. [8], 124, [2], 125-128, [2], 129-180 p.

[801] R. Boyle., *An Essay about the Origine and Virtues of Gems*. London, 1672. [16], 185 p. (i.e., 184, page 181 omitted).

successive superposition of layers of particles. He observed the geometric outlines of minerals, and made some observations about the cavities in stones, lined with minute crystals, remarking that they formed from a lapidifying juice (*succus lapidesceus*) of great purity. He also noticed the lamellar texture of many minerals and made a long, patient series of notes and descriptions about crystalline forms.

In 1688 Dominico Guglielmini [1655-1710] extended Steno's law to other manufactured crystals, such as nitre (potassium nitrate), common salt (sodium chloride), alum (hydrated aluminium potassium sulfate) and blue vitriol (copper sulfate).[802] He observed that the crystals he created from solution all had fixed angles to their interfactial angles, which was a unique form restricted to each species. From his experiments he stated that no matter how large, crystals were formed from innumerable similar smaller crystals, and that these, fitting together, leave openings that give porosity to the crystal or contain water which may be expelled by heat. Guglielmini continued his studies on crystals and in 1705 proposed four basic forms for the particles of salts: the cube, the hexagonal prism, the rhombohedron and the octahedron, which combined to form the various different salts. Guglielmini's observations helped pave a clear path for the science of crystals to expand from a collection of speculative facts to the outlines of a great science. The next stage of growth was now about to usher in the profound and varied facts which built up crystallography, and laid in chemical composition the foundation of a rational system.

### 8.1.2 Eighteenth Century

**REWORK:** The 18th century was dominated by the development in the fields of mathematics, physics, chemistry and biology. Progress was also made in crystallogrpahy; however, only a few scientists studied aspects of crystals. In 1723 Moritz Anton Cappeller [1685-1769] proposed a morphological classification of minerals and rocks, and was one of the first to use the word 'crystallography' in his treatise, *Prodromus Crystallographiae de Cristallis Improprie sic dictis Commentarium* (1723).[803] He enumerated the structural types of mineral occurrences as spherical, conical, wedgeshaped, fibrous, micaceous, and lenticular.

A writer who held many mystic beliefs, Emmanuel Swedenborg [1688-1772] composed works on natural philosophy in which he developed extremely complex and confused views of the structure of matter.[804] For example, he believed common salt to consist of the water balls strongly connected with chains of solid salt molecules, which occupy space between the balls.

In his chemical reseach Hermann Boerhaave [1688-1738] noted the external forms of natural and artificial crystals, and rejected the common opinion that they are consolidated from extremely dense water, although he does not say how they are formed.[805]

Quartz crystals are described by Johann Jacob Scheuchzer [1672-1733] in his account of an excursion through Switzerland. He considered crystallography an interesting but difficult subject, that he had pursued for sometime, and had not discovered a path through its labyrinth. He gives a summary of all observations back until Pliny, and describes the different colored varieties including brown, black, yellow (citrine), purple (amethyst), red, and green. He notes that the group of precious stones composed of rock crystal and its varieties, do not have many differences between the varieties, other than variations in hardness and luster. When Scheuchzer made the connection that amethyst was related to rock crystal, it would seem only natural that he would come to the fundamental question, are they both of the exactly same composition?, but he never asks this question. He also described numerous crystals with inclusions of other crystalline substances, impressions, channels, water drops, etc. and

[802] D. Guglielmini., *Riflessioni Filosofiche Dedotte dalle Figure de' Sali*. Pisa, 1688. [4], 39, [1] p., one plate.

[803] M.A. Cappeller., *Prodromus Crystallographiae de Cristallis Improprie sic dictis Commentarium*. Lucern, 1723. 43 p., 3 engraved plates.

[804] E. Swedenborg., *Principia Rerum Naturalium*. Leipzig, 1734. 3 vols.

[805] H. Boerhaave., *Elementa Chemiae*. London, 1702.

calls Switzerland the true fatherland of rock crystal. As to the origin of rock crystal Scheuchzer supports the ancient belief that an icy environment such as that found in the Swiss Alps made the dense crystallization of water easy, relative to elsewhere. He also criticizes Steno's view that quartz develops from the crystallization out of a fluid.

Louis Bourguet [1678-1742] cast aside the ancient, childish notions that minerals originated from seeds and germs, in his *Lettres Philosophiques sur la Formation des sels et des Crystaux.*[806] He does not regard stalactites as subterranean vegetable growths and he incorporates the efflorescences of various salts with minerals, whereas others had separated them. He properly separated fossils from minerals, recognizing that these so called petrifications were derived from once living organisms, and therefore not actually a mineralogical substance. Such distinctions were of great significance to the whole methodology of mineral studies. About the form of cystals, he believed they were composed of tiny triangularly shaped molecules that built up triangular tetrahedrons, three-sided prisms or similar plates that accumulated together to build the crystal. It was sufficient Bourguet contented to observe triangles on the pyramidal faces of Quartz as well as alum to see the proof of his theory.

In a description of a cave system, which discussed how the various rock formations were created, Joseph Pitton de Tournefort [1656-1708] believed that stalagmites were akin to petrified trees. Because they displayed such curious and suggestive forms, he held the view they were not deposited by water at all but grew from some hidden seed contained in the host rock like a plant, and furthermore the stalagmitic formation drew its nourishment from the same host rock.[807] In a similar view, he thought aggregates of crystals were like the flowers of the various salts, and were not recognized for their true nature because the particles forming them were too small.

The crystal structure of calcite and gypsum were studied by the mathematician and physicist Gabriel Philippe de la Hire [1677-1719]. In a treatise from 1710 he described very exactly the form of calcite called Iceland spar, determining the vertical angle formed by two planes of the rhombohedron at 105° and also examining double refraction.[808] He next turned his attention to talc, as he called it; the same material which was used in the manufacture of plaster of Paris. That it was a mixture of natural gypsum was at the time still not known. La Hire described the arrow-shaped hemitropes, determined the cleavage direction of gypsum, like Bourguet, thought that the crystals were composed from triangular flakes, and measured its angles at 50°, 60° and 70°. He also investigated the refraction of gypsum and found it to be doubled, but much weaker than Iceland spar.

Dortous de Mairan [1678-1771] in his *Dissertation sur la Glacé* (1716) speculated that salt, pyrites, and snow were formed from needleshaped molecules.[809]

John Hill [1707-1775] maintained that the double refraction is specific only to transparent bodies, which are composed from rhombohedral parts. He then gives a list of bodies he has examined that show the property: (1) Talc, which in thick masses elevates the line, (2) Selenite, (3) Rock crystal (quartz), and (4) Calc spar (calcite). He gives careful attention to the crystal forms he observes in limy spars, discussing their formation. He believed that Linneaus' hypothesis that a salt determines the ultimate form of a crystal was erroneous thinking that if one were to go so far as to assume that a containiment, even with it is undetectable, would form the crystal, then one

[806] L. Bourguet., *Lettres Philosophiques sur la Formation des sels et des Crystaux.* Amsterdam, 1729. xliv, 220, [12] p., one plate.

[807] J.P. de Tournefort., "Description du Labyrinthe de Candie avec quelques observations sur l'accroissement et sur la Generation des Pierres," *Mémoire de l'Académie Royale des Sciences*, **1702**.

[808] G.P. de la Hire., "Observations sur une espèce de talc qu'on trouve communément proche de Paris au-dessus des bancs de pierre de plâtre," *Mémoires de l'Académie Royale des Sciences*, **1710**, p. 341-352.

[809] Dortous de Mairan., *Dissertation sur la Glacé ou Explication Physique de la Formation de la Glacé et de ses divers Phénomènes.* Paris, 1716. • R. Hooykaas., "Kristalstreping en kristalstructuur," *Chemisch Weekblad*, **47** (1951), p. 1-7.

must consider the appearance of crystallization as proof that it contained the hidden salt.

Johann Gotschalk Wallerius [1709-1785] in *Mineralogia, eller Mineralriket* (1747) distinguished between the causes of crystallization and the causes of the forms of crystals, stating that form was related to the kind of metal contained and not to the salt as Linneaus surmised.

The Russian genius Mikhail Vasilievich Lomonosov [1711-1765] in his work *On the Genesis and Nature of Saltpeter* (1749) called attention to the constancy of the interfacial angles in nitre crystals, and explained their form by the densest packing of spherical particles. However, his work had no practical influence on the development of crystallography, because it was written in Russian, and was only recognized at the beginning of the 20th century as an important crystallographic work. Rudjer G. Bošković (Boscovich) [1711-1787] (1755) supported the idea that crystals were formed by molecules connected by attractive and repulsive forces, which was for the time, a very advanced idea.

The German mining professional Johann Friedrich Henckel [1678-1744] wrote about the metals as if they possessed animate affections, and assigned to them a certain moral order, making these particular affinities and unions something akin to love and friendship. He considered the crystal shape of some minerals such as pyrite to be useful in distinguishing its species. He also recognized that the cubic form of pyrite remained constant in terms of its angular arrangement.

Franz Ulrich Theodosius Aepinus [1724-1802] studied the pyroelectric effect in tourmaline and attempted to relate the property to the axes of the crystal (1756) (see §——)

The Swiss mathematician Leonhard Euler [1707-1783] published celebrated works of mathematical theorems on polyhedra and on transformations that more than a century later became the basis for fundamental research in geometrical crystallography. The earliest of these, published in 1752, was his discovery that for any 3-dimensional polyhedron the number of faces (F), edges (E) and vertices (V) are related by the formula: $F - E + V = 2$. He proved in 1765 that a product of two rotations about intersecting axes is itself a rotation, and that every proper motion is a product of a rotation and a translation. The significance of geometric transformation was not yet established in crystal science and the value of Euler's studies was not fully realized until the more general study of configurations used in crystal structure analysis that lay far in the future.

In 1767 Christian F. Westfeld [1746-1823] expressed the opinion after experimenting with cleavages of calcite that the mineral was composed of minute rhombohedra molecules.[810] Nearly simultaneously, Johann G. Gahn [1745-1818], a student of Torbern Bergman [1735-1784], made an identical observation. Showing how a scalenohedron crystal of calcite based upon a rhombohedron cleavage could be formed, was, however, first published by Bergman himself in 1773.[811] This was an important practical and theoretical step in crystallography, which conclusively showed that the formation of at least one mineral could be attributed to be the result of the superposition of layers of minute parallelepipedic shaped particles on an original parallelepipedic nucleus.

Carl Linné (*Latinized*, Linneaus) [1707-1778], incorporated minerals in his general classification of nature from the first appearance of his famous *Systema Naturae* published in 1735. Throughout his life, he continued to study minerals intensely, trying to use their external characteristics to place them with in a system of classification like he had so successfully systematized plants and animals. For his morphological approach that argued strongly for classifying crystals according to their shapes, Linné was called the founder of the science of crystallography by both Romé de l'Isle and Haüy, although he held a strong belief in the idea that minerals procreate and grow like vegetatbles.

[810] C.F. Westfeld., *Mineralogische Abhandlungen*. Göttingen, 1767.

[811] T.O. Bergman., "Variae Crystallorum Formae a Spatho Orthae," *?????????????*, **??** (1773), p. ??-??. • *ibid.*, *Physical and Chemical Essays*. Translated from Latin by Edmund Cullen. London, 1784. 3 vols.

In 1768, in the third volume of his *Systema Naturae*, which was the last full statement he gave on the subject, Linné applies his morphological approach favoring it over other physical or chemcical examinations when he classifies crystals into classes, rders, genera and species. Relying on the external form of the crystals he groups together those that are cubic, hexagonal, octahedral, and rhombic dodecahedral. Linné approach to sorting crystals by external form had tremendous impact on future crystallographers.

The German mineralogist Johann Karl Gehler [1732-1796] emphasized the importance of the external and physical properties of crystals to distinguish individual mineral species (1757).[812] This work would in 1774 influence the German mineralogist Abraham Gottlob Werner [1750-1817], who was greatly impressed by Gehler's book, to write his own treatise on determinative mineralogy, which appeared in 1774 under the title *Von den äusserlichen Kennzeichen der Fossilien*.[813] Expressing his own conception of crystals, Werner states that their morphology was based on six, instead of four, primary forms: icosahedron, hexahedron, prism, pyramid, plate and lens. Otherwise, he apparently was not very much interested in crystallography, writing very little on the subject.

In 1772 Jean Baptiste Louis Romé de l'Isle [1736-1790] published the first edition of his widely acclaimed treatise on crystallography which was a 'state of the art' account of minerals and crystals.[814] He acknowledges in his preface that to a large extent he is following in the footsteps of Linnaeus. Recognizing that the forms of even very diverse crystalline substances could be very nearly the same, he considered that there was some hidden affinity in the material that linked them together. He believed in a molecular theory of crystallization, that crystals were built from the juxtaposition of identical molecules that arranged themselves in a distinct pattern, and that the quality of perfection in the crystal ultimately depended on the purity of the solution from which it formed. He accepted the idea that the figure of a mineral crystal was due to a specific salt that was present, but did not wholeheartedly accept the theory. Pure metals he noted formed crystals, but no chemical technique had yet rested a salt from them, suggesting that the saline principle was erroneous, but failure to locate the salt did not mean the theory was wrong. Finally he remarks that it is a controversay he does not want to enter. After giving a full treatment of crystal analysis for the known minerals, in an appendix he lists 110 crsytal forms that have been observed. Quite rightly Romé's book is said to have given the first definition of crystallography as a new science.

After the good reception Romé's book received, preparations for a new much expanded edition were undertaken. Arnould Carangeot [1742-1806], a student and assistant to Romé de l'Isle helped in preparing the polyhedral terra cotta clay models of the crystal forms that would be illustrated on the plates. Frustrated at not being able to exactly render a complex crystal of quartz, Carangeot cut from cardboard a template that represented the interfacial angle two faces formed with one another. Much to his suprise, he found that all of the faces of the prism had exactly the same angle, eventhough the quartz crystal looked bizzare. Applying his template to all the other quartz crystals on hand he recognized with satisfaction that the angle remained constant. Further templates and experimentation led him to conclude that for all crystals, each pair of adjoining crystal faces had a specific value to their angle, regardless of how distorted the crystal might appear.[815] After being shown how the templates accurately determined a crystallographic angle, Romé de l'Isle realized immediately the importance of

[812] J.K. Gehler., *De Characteribus Fossilium Externis*. Lipsiae, 1757.

[813] A.G. Werner., *Von den äusserlichen Kennzeichen der Fossilien*. Leipzig, 1774.

[814] J.B.L. Romé de l'Isle., *Essai de Cristallographie*. Paris, 1772.

[815] A. Carangeot., "Goniomètre, ou mésure-angle," *Journal de Physique*, **22** (1783), p. 193-???. • *ibid.*, "Lettre à M. de Lametherie sur le goniomètre," *Journal de Physique*, **29** (1786), p. 226-???. • *ibid.*, "Lettre de M. Carangeot à M. Kaestner," *Journal de Physique*, **31** (1787), p. 204-???.

the achievement and, with the help of his pupils, created a general form of the device that could measure any angle, applying the new tool to all the crystals available in his laboratory. This confirmed the generality of the Law of Constancy of Interfacial Angles and in 1783 when the second edition of Romé's *Cristallographie* was published it used the new law and new contact goniometer as its foundation stone.[816]

The application of goniometry is the principal difference immediately apparent in the second edition of Romé's *Cristallographie* compared with his earlier work. By the time of its publication, Romé had made crucial advances towards a quantitative crystallography. He was, for example, now abot to list over 450 possible crystal forms, and provide for each accurate angle measurements between different crystal surfaces made with the contact goniometer. Armed with his law, he was able to somewhat elaborate on his definition of the primitive form and how it related to the external crystal, but Romé never made the theoretical leap to create an elegant theory from the information. Nevertheless, Romé captured information from his crystallographical laws and together with his broadened concept of the relationship between crystal form and chemical composition, he made the *Cristallographie* into the finest mineralogical treatise written to its time.

In this same period and only a year after the second edition of Romé's appeared René Just Haüy [1743-1826] published his first book on crystallography, *Essai d'une Théorie sur la Structure des Crystaux* (1784), which were certainly very heavily influenced by the works of Bergman and Romé de l'Isle.[817] He is considered the founder of modern crystallography because of his rigid mathematical approach to crystallographic problems that led him to announce the law of simple rational intercepts. It was, however, in the geometrical part of his *Traité de Minéralogie* (1801) that he presented his ideas in a more clear and complete form, adding a large number of crystal drawings to illustrate his theories. In it, Haüy brought together the advances in crystallography into a coherent structural theory, based on the structural unit, the *"molecule constituante"* (later renamed by him to *"molecule integrante"*). Haüy's model depicted crystals as built up out of these molecular units which were polyhedral in form. Haüy also theorized a common "nucleus" or "primitive form" for all crystals of the same "species." This primative form was often revealed by cleavage of a crystal symmetrically along its angles and edges. Highly influential in the development of crystallography, Haüy's researches and theories superseded all previous attempts, and these were presented in the author's own literary fluency. His work was recognized as the most important offered by France to the science of crystallography and mineralogy that placed the country at the forefront of the European nations in this science.

Pierre Clément Grignon [1723-1784] thought fire caused the fusion of metals, and slow cooling from the molten condition resulted in the production of crystals.[818] His view was that each body in the universe had a characteristic figure which, together with the chemical composition of the substance, made it a distinct individual. According to Grignon, material matter could not exist without form because both came into existence similtaneously, and endowed the material with its individual essence.

A French chemist Nicolaus Le Blanc [1742-1806] believed that careful chemical experimentation ought to shed some light on the mechanism of the process of crystallization, which was a new approach to the problem. He expressed the view that the true essence of crystallography should encompass the study of the conditions that give rise to crystal growth so that the form of a particular crystal might not only be explained but predicted.[819]

[816] J.B.L. Romé de l'Isle., *Cristallographie*. Paris, 1783. 4 vols.

[817] R.J. Haüy., *Essai d'une Théorie sur la Structure des Crystaux*. Paris, 1784. [8], 236 p., 8 folding plates.

[818] P.C. Grignon., *Mémoires de Physique: sur le Fer*. Paris, 1775, p. 476-481.

[819] N. Le Blanc., "Essai sur quelques phénomènes relatifs à la cristallisation des sels neutres," *Journal de Physique*, **28** (1786), p. 341-345. • *ibid.*, "De la Cristallotechnie ou

### 8.1.3 Nineteenth Century

**REWORK:** In the 19th century there was an explosion of crystallographic works dealing with both practical and theoretical aspects of the science. New instruments allowed the crystallographers of the era to gather accurate numerical data from natural specimens and develop a classification of crystal forms and from there a theory of crystal structure. Important advances were made in physical crystallography after the discovery in 1808 by Étienne Louis Malus [1775-1812] of polarized light by reflection. This discovery provided the basis for many theories and experiments that would build the foundations of optical mineralogy (see §——).

Nicolaus Leblanc who had proposed theories on crystal formation at the end of the 18th century further extended his theory, publishing the summation of his views in the *De la Crystallotechnie ou Essai sur les Phenomenes de la Cristallisation* that appeared in 1802.[820] In particular, he showed that when another chemical compound was mixed into a different pure compound, the form of the crystal of the combination could be considerablly different than either of the components individually.

By the early years of the 19th century, advances in chemistry were having an adverse effect on Hauy's insistance that each mineral species had a distinct molecule integrant and a unique chemistry. This could not explain anomalies such as the species calcite and aragonite. Both minerals have chemical compostion of calcium carbonate ($CaCO_3$), but each crystallizes in a different crystal system, and hence by Hauy's definition a different form of the primary particle. Tremendous efforts were made by Hauy's supporters to reconcile these facts and save his theory, but to little avail. The French Count Jacques-Louis Bournon [1751-1825], who had fled France to avoid being guillotined, relocated to London. There he wrote and had published a 3 volume treatise concerning the properties and relationship between calcite and its structural isomorph, aragonite.[821] Although quanatative analysis proved them to be chemically identical, examination of their physical properties showed aragonite to be harder, heavier and to possess a different crystal form, on which basis aragonite had been called a separate species by mineralogists who did not support Hauyian theories. Bournon wrote his work, his most important mineralogical contribution, to support the position that calcite and aragonite were separate mineral species, and that the final determination of whether a mineral is a distinct species relies on physical characteristics, not chemical properties.

The studies of François Sulpice Beudant [1787-1850] continued the crystallochemcial approach proposed by Le Blanc. He studied the dependence of exterior form on the conditions that existed during crystallization. Investigating the action of atmospheric pressure, the humidity of air, heat, concentration, volume of solution and electric current to the identical crystallizing solutions, he arrived at the conclusion that a change in the initial conditions rapidly affects the speed of crystallization and the ultimate crystal size, but it such changes are not reflected in their morphological form.[822] He did record that if other substances are introduced into the crystallizing fluid, changes would occur. For example, the aluminum alum, which crystallizes from a homogenous aqueous solution in the form of octahedrons, will crystallize from a nitric acid solution as cuboctahedrons. Beudant made similar studies with a wide range of materials, providing evidence of the existence of what are now termed solid solutions within in minerals. His research also played a positive role in the discovery of isomorphism.

In 1817 Johann Nepomuk von Fuchs [1774-1856] studied the morphological kinship

Essai sur les phénomènes de la cristallisation," *Journal de Physique*, **55** (1802), p. 296-313.

[820] N. Leblanc., *De la Crystallotechnie ou Essai sur les Phenomenes de la Cristallisation*. Paris, 1802.

[821] J.-L. Bournon., *Traité de Mineralogie*. London, 1808. Also released in the same year under the title, *Traité complet de la Chaux Carbonatee et de l'Arragonite*.

[822] F.S. Beudant., "Recherches sur les causes qui peuvent faire varier les formes cristallines d'une même substance minérale," *ADC*, **8** (1818), p. 5-50.

between two chemically similar minerals, aragonite (calcium carbonate; $CaCO_3$) and strontianite (strontium carbonate; $SrCO_3$) which showed a path to isomorphism.[823]

At the Berlin Academy in December 1819 Eilhard Mitscherlich [1794-1863] presented his important paper on isomorphism, which was immediately translated into French where it was published in 1820.[824] Modern chemical crystallography is considered to have originated with this work and on its extension to polymorphism in 1822. At that time the discovery of isomorphism and polymorphism ran against Haüy's hypothesis that crystallography was the dominate feature of mineral species, with chemistry playing a subservient role. An interesting correspondence between Haüy and Berzelius shows Haüy's strong opposition to the work of Mitscherlich.

Despite its advantages, Haüy's theory was not universally accepted by crystallographers outside France. The established German mineralogist Dietrich Ludwig G. Karsten [1768-1810] asked a young mineralogist, Christian Samuel Weiss [1780-1856] to help in the preparation of a German tranlation of Haüy's four volume *Traité de Mineralogie* (1801). It was a long process, extending from 1804 to 1810 before it was complete. Weiss did not however confine himself to a simple transfer of the original text. He includes his own views on the theory and appends an important article "Dynamische Ansicht der Krystallisation" (dynamic view for the crystallization) in which he introduced the important concept of anisotropy and stated the zone law which is the equivalent of Haüy's law of simple rational intercepts. The supporters of this study denied existence of atoms and asserted that material was formed by the opposite forces of attraction and repulsion (a view Weiss apparently maintained his entire life). This was a direct challanged to Haüy's theory.

Johann Jakob Bernhardi [1770-1850] conceived the idea of considering, instead of Weiss's faces or zones, the perpendiculars to the faces drawn from the centre of the system. He then poses the question of what is the smallest number of simple forms to derive all crystallization according to the simplest laws. This idea led to him first advancing the idea of crystal systems in 1808.[825]

Weiss defended a dissertation in 1809 *De Indagando Formarum Cristallinarum Charactere Geometrico Principali* (About The Method Of Determining The Basic Geometric Nature Of Crystalline Forms) that first distinguished between seven systems of crystals differing in the number and nature of their axes of symmetry. In Weiss's scheme, any face could be defined by the ratio of the intercepts cut off by it on the axes of symmetry. He proposed the description of the faces of crystals in relation to three main axes that he called a, b and c, whose designation and orientation are still adopted today. Two other important works of Weiss were *De Charactere Geometrico Principali Formarum Crystallinarum Octaëdricarum* (1809) and 'Uebersichtliche Darstellung der verschiedenen natürlichen Abteilungen der Kristallisations-Systeme' (1815). In these works he proposed the classification of crystals in four main systems, with subdivisions, but he only considered crystallographic axes mutually perpendicular.

At the time tremendous attention was given to the description of crystal morphology. The importance of accurate measurements of crystal angles was full recognized, but the contact goniometer could only be used on large crystals and even so was only accurate to about 1/2 a degree. In 1809 the English mineralogist, William Hyde Wollaston [1766-1828] invented a reflecting goniometer that allowed for a magnitude of greater precscion in the measurements. Soon other models of the goniometer were introduced so that measurements could be made from even the smallest of crystals (see §14.5 for a full description).

Johann Friedrich Ludwig Hausmann [1782-1859] introduced spherical trigonometry

[823] J.N. von Fuchs., "Ueber den Arragonit und Strontianit," *J. Chem. Phys. JSC Schweigger*, **19** (1817), p. 113-137.

[824] E. Mitscherlich., "???????," *??????*, **??** (1819), p. ??-??. • *ibid.*, "???????," *??????*, **??** (1820), p. ??-??.

[825] J.J. Bernhardi., "Darstellung einer neuen Methode, Kristalle zu beschreiben," *Journal für die Chemie und Physik von A. F. Gehlen*, **5** (1808), p. 157-198, 492-564, 625-654.

as a method for describing crystal forms. Later his ideas were developed by Franz Ernst Neumann [1798-1895] which led to his introduction of the gnomic and stereographic projections to crystallography in his *Beitrage zur Krystallonomie* of 1823 (see §14.7). The concept was reintroduced by Johann G. Grassmann in 1829, but it was not until William Hallowes Miller and Friedrich August Quenstedt applied Neumann's approach that it became standard in crystallographic studies.

Extending the work of Weiss, Friedrich Mohs [1773-1839], in his *Grundriss der Mineralogie* (1822), considered crystal forms where the three axes were oblique to each other and proposed six crystallographic systems.

Using the systems of notation of Whewell (1825) and others, William Hallowes Miller [1801-1880] exploited the advantages of stereographic projection to such good result that his *Treatise on Crystallography* (1839) rapidly eclipsed all other works on the subject. His crystallographic notation is now universally adopted.

A former student of Wiess, Gustav Rose [1798-1873] took an active part in the discovery of isomorphism, helping to make crystallographic measurements on a reflecting goniometer. He continued his mineralogical studies, accompanying Humboldt on a famous journey through the regions of Siberia, and publishing a mineralogical-geological description of the lands they travelled through.[826] He also continued to study the geometric properties of crystals which he summerized in his book, *Elemente der Krystallographie* (1833), later translated into French and Russian. He gives similtaneously the characteristics of minerals together with crystallographic data. The engravings, which illustrate text, depict crystals in the orthogonal projections. Rose's discussion deals with the precise descriptive study of mineral forms with the accumulation of goniometric data. In 1844 he published a classic monograph on the crystal system of quartz.[827] This is the first large monograph about the morphology of quartz, in which Rose concludes that it should belong to the "tetartohedral" subdivision of hexagonal system, thereby recognizing its trigonal characteristics while it is in the hexagonal class.

In 1870 Paul Heinrich von Groth [1843-1927] examined the effect of change in crystal form when certain elements are substituted in the chemical composition of crystals, and called it "morphotropism."

In 1879 François Ernest Mallard [1833-1894] introduced his own theories and methods that replaced Hauy's laborious computations with elegant and rapid calculations.[828] He also proposes an ingenious methods of zones, and makes extensive use of stereographic and gnomic projection to disentangle difficult crystallographic problems. Throughout his work Mallard developed and extended Bravais' lattice theory, especially with respect to the importance of crystal faces and twins.

In the last decade of the century, Vernadskii [xxxx-xxxx] showed that polymorphism was a general phenomenon (1892).

A. Werner proposed in 1893 a coordination theory for the arrangement of atoms in crystal structures, that provide a deeper insight into structural properties of crystals.

Other physical characteristics of crystals, including their thermal, mechanical, electrical and magnetic properties, were studied extensively during the 19th century. Among the many research workers are Stokes (1851), W. Thomson (Lord Kelvin) (1854), J. Curie & P. Curie (1880) and Voigt (1876).

Others to include:
William Whewell [1794-1866]
Henry James Brooke
Abraham Gotthelf Kästner
Christian Kramp
Armand Lévy [1794-1841]
Karl Caesar von Leonhard
August Breithaupt [1791-1873]
David Brewster [1781-1868]
Wilhelm Haidinger [1795-1871]

[826] G. Rose., . Berlin, 1837-42. 2 vols.

[827] G. Rose., *Über das Krystallisationssystem des Quarzes*. Berlin, 1844. [4], 58 p., 5 plates.

[828] F.E. Mallard., *Traité de Cristallographie*. Paris, 1879-84. 2 vols., plus atlas.

Johann Friedrich Hessel [1796-1872]
Johann Gottlieb Christian Nörrenberg [1787-1862]
Carl Friedrich Naumann [1797-1873]
Martin Heinrich Klaproth [1743-1817]
Moritz Ludwig Frankenheim [1801-1869]
Arcangelo Scacchi [1810-1893]
Auguste Bravais [1811-1863]
Quintino Sella [1827-1884]
Louis Pasteur [1822-1895]
Gerhard vom Rath [1830-1888]
Christian Friedrich Martin Websky [1824-1886]
Friedrich August Genth [1820-1893]
George Jarvis Brush [1831-1912]
Samuel Lewis Penfield [1856-1906]
Leopold Heinrich Fischer [1817-1886]
Victor Moritz Goldschmidt
Gabriel Auguste Daubrée [1814-1896]
Schoenflies
Fedorov

### 8.1.4 Twentieth Century

**REWORK:** Crystallography by the beginning of the 20th century was a mature science. Atomic theory was giving a picture of what built, structurally, the internal material of the crystals, but no scientist thought that it it would be anything more than conjecture. It was therefore the province of the crystallographers to continue to explore what they could observe and construct theories to explain their observations.

In a large monograph on crystal science, Georges Friedel [1865-1933] summerized all that was known at the time.[829] He introduced much clarity to the study and helped develop theoretical crystallography. His research led him to make many important innovations, including the reticular theory published in 1907.[830]

In 1912, crystal science was turned on its collective head by the development of X-ray diffraction that allowed experimenters and theorists to gain direct information about the internal structure of crystals (see §8.3). This innovation altered crystallography in a positive direction, and allowed it to bloom as its own discipline.

Crystal morphology was still of practical study. Viktor Goldschmidt [1853-1933] in 1913 capped his long and distinguished career as a distinguished crystallographer with start of the publication of his encyclopedia of crystal morphology, *Atlas der Krystallformen*, whose purpose was to collect, index and reproduce in one work all the crystal forms observed for every mineral species. This work was the keystone to the author's crystallographic research. Together with the *Index der Krystallformen der Mineralien* (3 vols., Berlin, 1886-91) and *Kristallographische Winkeltabellen* (Berlin, 1897), it forms the last segment of a trilology Goldschmidt had intended to publish from the start of his carrer, and which incidently defined modern crystal morphological studies. In the preface to the text, Goldschmidt explains the broad standpoint that has led him to develop this work. His desire was to bring together the material necessary for solving many of the problems of crystals and their growth, particularly with respect to habit, the frequency of occurrence of certain forms and the relative size of the faces. The tremendous depth of the work is astonishing, with the crystal forms of many mineral species represented by several hundred crystal drawings. The text is arranged alphabetically by mineral name, and consists of two parts. The first and most important of these are the plates, for they create the esthetic value of the work. Reproductions of many thousands of crystal drawings illustrate graphically all the variations in form observed for every mineral. Supporting these figures is the text, which lists the various characteristics of the minerals, and gives a detailed accounting of the locality and exact reference sources for each figure pictured.

Finally, by the second decade of the century, the development of lattice dynamics through application of quantum theory, by Max Born [1882-1970] and others gave a working model of how the atoms in a crystalline structure coexist with one another.

[829] G. Friedel., *Étude sur les Groupements Cristallins*. Paris, 1904. 485 p., illus.

[830] G. Friedel., . Paris, 1907.

### 8.1.5 Twinned Crystals[831]

**REWORK:** The morphological study of crystals in the 19th century tended to be limited to descriptions of ideally formed crystalline forms. This was particular true of the German school headed by Weiss and Mohs. However, attempts to translate from idealized, theoretical models to natural crystals, with all of their complications and imperfections, was not easy. In fact, for a long period such comparisons, which usually conflicted with the models developed by the morphologists were not attempted. It was only much later that the value of comparisons between theory and nature was recognized that the physical study of real crystals was intensified.

One pressing problem for the theorists was an explanation of naturally occurring crystallographic intergrowths. Apart from ordinary crystals, these are composite crystals consisting of two (usually equal and similar) crystals united in a symmetrical intergrowth, usually with the individual crystals in reversed positions with respect to each other. These are called twinned crystals, or 'twins' for short. A new symmetry operation (called a twin element), which is lacking in a single untwinned crystal, relates the individual crystals in a twinned position. But it was not until the introduction of X-ray analysis that this atomic arrangement was confirmed. In fact crystallized specimens of this type had been observed, described, and sometimes even illustrated since the middle 18th century, and they required explanation, which was a thorny problem for crystallographers.

In his *Essai de Cristallographie* (1772) J.B.L. Romé de l'Isle emphasized the primacy of form in his definition of a crystal to be any mineral of polyhedral shape and had even given approximate interfacial angles for some species, together with many illustrations of natural crystals. After the invention of the contact goniometer and the discovery of the law of constancy of interfacial angles of minerals of the same species, Romé in the second edition of his *Cristallographie* (1783) determined six primitive forms, and showed how they could by truncation be modified to produce secondary forms to mimic the variation of forms seen in real crystals. During this study he was also the first to single out twinned crystals for special attention. Romé describes the mineral species staurolite, a mineral that frequently forms distinctive twins, calling them such specimens a 'macle.'[832] He then goes on to say that he calls any crystal a macle that consists of two crystals, one of which is inverted and attached in a reverse direction.[833] He further clarifies that specimens of this type are not a simple group of two or more crystals, but that the crystals are mirrors of each other.[834] He gives further examples of gypsum, harmotome, feldspar, and cassiterite as crystals that could twin.

Even before the discovery of the goniometer, the Swedish chemist and mineralogist Torbern Bergman had attempted to apply his theory of a standard 'nucleus' as the building block of crystals to form a polyhedra of a macro crystal.[835] He had successfully applied it to his description of calcite, but the analogous

[831] Other historical information may be found in: R.W. Cahn., "Twinned crystals," *Advances in Physics*, **3** (1954), no. 12, p. 202-445. • M. Löffler., "Strukturelle und kristallochemische Grundlagen der Zwillingsbildung," *Neues Jahrbuch für Mineralogie*, Abteil A, **68** (1934), p. 125-193. • M. Senechal., "Brief history of geometrical crystallography" (pp. 43-60), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990. • I.I. Shafranovskii., Историиа кристаллографии XIX век [Istoriia kristallografii XIX vek]. Leningrad, 1980, p. 193-198. • F. Wallerant., *Groupements cristallins*. Paris, G. Carré & C. Naud, 1899. 81 p., illus. [Contains a detailed investigation of crystallographic twins, p. 20-27.]

[832] *Macle*, meaning spot or mark, was then a synonym for chiastolite (a variety of andalusite), meaning cross-wise, alluding to the black center which a crystal often shows when cut into sections, and showing a distinctive cross. Macle was used as a synonym in the French literature in 1751 by Christophe Paul Gautron de Robien in his *Nouvelles Ide'es sur la Formation des Fossiles* (1751).

[833] "J'apelle macle tout cristal, qui est produit par l'inversion en sens versus Irish de l'une moitiers de ce meme cristal." J.B.L. Romé de l'Isle., *Essai de Cristallographie*, 1783, p. 93.

[834] "Ce n'est point un cristal simple corn un groupe de deux ou de plusieurs cristaux, ou meme de deux moitiers retournes d'un meme cristal." J.B.L. Romé de l'Isle., *Essai de Cristallographie*, 1783, p. 93.

[835] T.O. Bergman., "Variae crystallorum formae a spatho orthae," *Nova Acta Regiae Soc. Sci. Ups.*, **1** (1773), p. 150-155.; English translation by E. Cullen (1784) contained in T. Bergman, *Physical and Chemical Essays*, London, 1784. 3 Vols.

construction he applied to a cruciform staurolite twin failed. At that time, the identification of twinned crystals as polycrystalline structures had not been made.

Later, Abraham Gottlob Werner mentions twins for the first time in his description of the Pabst von Ohain mineral collection. He notes that there were "Zwillinge" crystals among the collection's specimens of chalcopyrite ("Kupferkies"), calcite, gypsum, and harmotome.[836] This description was translated literally into French as 'jumeaux' by his students J.P. Vanberchem-Berthout and H. Struve in their translation of Werner's handbook of mineralogy.[837] They associated it with the same mineral examples. Ludwig August Emmerling also noticed twins of gypsum with both sides of a crystal flaring at opposing angles.[838]

Apparently, René Just Haüy remained unaware of the use of "jumeaux" to describe twinned crystals, because he does not mention it, instead he complains of Romé's use of the expression of macle.[839] He tries to replace the descriptor macles by different designations which had been attached to a variety of exterior characteristics. He classifies twins as "formes sécundaires" and divides them into "transposé, hémitrope, rectangulaire, obliquangle, sexradié, cruziforme, genicule et triglyphe".[840] The cornucopia of designations he had to use to describe the various forms encountered illuminates the fact that he had trouble incorporating twins into his structural theory of crystals. Haüy made wide use of the term *hemitropie* that stressed the idea that twins consisted of two crystal halves turned against each other. Applying his theory of crystal structure he also realized that there was a twin face from which the two halves formed creating the twin. This caused him to isolate two types of twin, interpenetration twins and penetration twins. In the later case he also noticed that penetration twins have a higher degree of symmetry in comparison to the symmetry of the single crystals that enter into the adhesion.

Pupils of Werner became the guardians of mineralogy in the early 19th century. They also treated twins in their writings. Christian Samuel Weiss who developed a three dimension coordinate system to mathematically understand crystal forms, also took into account distorted and twinned crystals in his theoretical model. He was therefore able to fully define the twin laws for feldspar ("Baveno" and "Dauphiné"), pyrite ("Iron Cross"), quartz ("Brazil Law"), and chabasite.[841] He expressed the laws as the position of two individual crystal joined along a common boundary surface. He also suspected that distorted crystals of calcite and quartz might form as a consequence of twinning. He also gives a full description of staurolite twins, noting that there is a higher degree of symmetry in the combination then is seen in the in the individual crystals.

Friedrich Mohs, who had a spirit of arranging, brought for the first time a classification of twins based on their features. He does not like Haüy's use of hemitrope crystals to describe such specimens preferring instead the use of twin crystals saying that the former term refers to only a single crystal whereas the later deals with two individuals.[842] Mohs refers to four types of twinning, indicating that the twin plane does not always have to coincide with a specific crystalline face. In connection with this, he assumed that twins occurred to specific laws of crystal formation.

1. The face of composition to be parallel to a face of crystallization, and the axis of revolution, perpendicular to it, to be at the same time an axis of crystallization.

[836] A.G. Werner., *Verzeichnis der Mineralien des Kabinetts des Berghauptmanns Pabst von Ohain*. 1791.

[837] J.P. Vanberchem-Berthout and H. Struve., *Principe de Mineralogie*. 1794.

[838] L.A. Emmerling., *Lehrbuch der Mineralogie*. 1797.

[839] "Romé de l'Isle les nommoit macles, mais ce nom se trouve déjà appliqué â une éspèce de mineral très commune, j'ai cru devoir en éviter le doubles emploi." R.J. Haüy., *Traité de Minéralogie*. 1801, p. 106.

[840] R.J. Haüy., *Traité de Minéralogie*. 1801., p. 201.

[841] C.S. Weiss., *Kristallographische Abhandlungen*. 1816.

[842] F. Mohs., *Grundriß der Mineralogie*, 1822, p. 300.; English translation by W. von Haidinger, *Treatise on Mineralogy*, 1825, **1**, p. 243.

2. The face of composition to be parallel to a face of crystallization, and the axis of revolution, not parallel to any axis of crystallization.
3. The face of composition is perpendicular to an edge of the crystalline form, and the axis of revolution parallel to this edge.
4. The face of composition is parallel to a face of crystallization, but the axis of revolution lies in the same face, and coincides with an axis of the crystalline form.[843]

Interestingly, Mohs in his classification does not include a rotation axis along the axis of the contact twin, which shows how difficult twin laws were to observe in nature.

Developing on the models of Weiss and Mohs, Carl Friedrich Naumann introduced analytic-geometrical methods to crystallography and in this way treated also the twin problem. In his textbook of crystallography he distinguishes twins with the mutually inclined (not parallel) axes and twins with parallel axes.[844] The latter are formed only by crystals with 'Merohedry' forms.[845] Two crystals with the faces of hemihedral forms (i.e. the having the half number faces in comparison with the number of faces of general holohedral form) are oriented relative to each other so that the totality of two hemihedral forms form summary holohedral (holohedral) form. This phenomenon had been noted by C.S. Weiss. Mohs differentiates sharply between twins with parallel and crossed axes. He shapes his terms just as sharply 'Juxtapositions' and 'penetration twins', implying that the parts are in such intimate contact with each other over part of their bounding surfaces that they cohere, this cohesion being often, though not always, as strong as the internal cohesion of a single crystal (Cahn, 1954). Naumann sets up the requirement that the line of rotation must always be a crystallographic component, thus either one of the axes of the crystal structure or an edge or a surface-normal of one of their basic shapes. If twins are rotational along two different twin axes (i.e. Carlsbad twins), Naumann speaks of a twin axis, as differentiated from a normal axis.[846]

The Franz Neumann school essentially maintained Naumann's point of view concerning the twin possibilities, but looked for their solution on the basis of ball projection and spherical trigonometry. This is the approach that was followed in the later work of Wilhelm J. Grailich and Albrecht Schrauf. They believe the axis of twinning is a common axis between the two individual crystals and those of the surfaces one for the axis of the other one.

The crystallographic work of the beginning half of the 19th century period belongs to a study of the theoretical structures through mathematics (§8.4.). The research of the crystallographers strive for an abstract crystallography, which has little in common with practical mineralogy. They occupied themselves with developing methods to calculate ideal shapes and for deriving all of the possible crystallographic projections. Twin elements were certainly incorporated into their models and computations. However, these were theoretical studies that had little influence or value to the hands-on mineralogists.

Most of the research on twins carried on by mineralogists involved describing in detail the crystallographic forms observed and make statements about twin laws. Mineralogists in studying the precise characteristic of the numerous twin formations of minerals defined specific and commonly occurring type, i.e. Dauphiné and Brazil twins of quartz, twins of feldspar, calcite, and other minerals. These authors were limited to the statement of twin laws, to scrupulous descriptions and idealized images of regular crystalline adhesions. The question about the reasons for the appearance of such formations by them was not touched upon. With the notation developed by William Hallows Miller

[843] F. Mohs., *Grundriß der Mineralogie*, 1822, p. 300.; English translation by W. von Haidinger, *Treatise on Mineralogy*, 1825, **1**, p. 243.

[844] C.F. Naumann., *Lehrbuch der reinen und angewandten Kristallographie*, 1830.

[845] Merohedry, from Greek origin, implies that each component crystal has fewer faces than it would have if the structure had the highest symmetry possible for the lattice on which it is based.

[846] C.F. Naumann., *Lehrbuch der reinen und angewandten Kristallographie*. 1830.

that simplified the description of crystals the designation of twin elements was also indirectly advanced.[847]

Studies such as this led Gustav Rose to consider specimens with two unequal crystals from the hexagonal systems not as real twins, but rather as parallel grows, which simply looked like twins.[848] But little theoretical information came from the practicing mineralogists.

In 1850 Auguste Bravais was able to go beyond Haüy's demonstration of the construction of the various crystal forms to a prediction of the order of their importance.[849] However, this theory accounted not only for holohedral forms, but twinning and Merohedry, could be explained, he argued, by taking into account the symmetry of the (supposedly polyhedral) 'crystallographic molecules' positioned in parallel orientation at the lattice points. This is the first time an attempt at the theoretical explanation of the phenomena of twinning was put forward, being based on his study about the lattice and molecular structure of crystals. In his treatment three types of formation are distinguished: molecular twins ('Merohedry'), molecular inverted twins, and reticular grid twins ('Hemitropie').

1. Complex particles – of crystalline molecules – possess only part of the elements of the elements of the symmetry of the lattice. The absent elements of symmetry include the twofold axis. In one and the same lattice such particles can be located differently (in the case of hemihedry they are possible two orienting, while in the case of tetartohedry-four). At the same time orienting by one of the particles can be derived from orienting of another particle via pogates on 1806 all around absentees in the particle, but the being present in the lattice twofold axis. Thus, in different parts of the same lattice of particles ('molecules') they can have different orientations. Hence it follows that two uniform 'Merohedrical' crystals can mutually form symmetrical to each other. Moreover, one of them is derived from the other by turning 180° around the common axis. Minerals in this group include pyrite that is often found twinned with respect to a (110) symmetry plane, in the form of contact or more usually penetration twins. Dauphiné twinning in quartz is another example of twinning by merohedry.
2. This type is connected with the crystals, which possess two types of particles, conversely equal (inverted) relative to each other. As in the preceding case, these particles can be placed in two different parts of the same lattice and also form two mutually forming crystals. Twins by pseudo-merohedry are legion among minerals and artificial compounds. Staurolite twins are of this type as are those of albite.
3. *Twinning by Reticular (or Lattice) Merohedry* is mainly restricted to cubic crystals. This type is characterized by the entire totality (i.e., the lattice) together with the grid and molecular polyhedrons is turned 180°. The growth twins in galena, fluorite, diamond, silicon and germanium, the annealing twins in brass, and the mechanical twins in iron and molybdenum, are all of this type. The third type, which is completely based on the lattice structure of crystals and the imposition of grids, preserved its value as the simplest visual explanation of the mechanism of twinning. It is used now in the courses of elementary crystallography.

One cannot fail to note the depth of approach that Bravais brings to the understanding of twins. By using his theoretical lattice and replacing his molecules with the totalities of points (atoms), he was able to construct a structural interpretation of twin formations.

Teodor von Gutzeit wrote his very rare *Das Gesetz der Zwillingsbildungen am Stein* to describe these crystallographic rareties.[850] He recounts the known facts about twins and observes that the most important thing about twins is the twinning surface that he calls "Sehebene".

The space grid structure of the crystals was taken up by Leonard Sohncke suggesting that twins formed due to an unstable equilibrium positions between the molecules of the crystal.[851]

[847] W.H. Miller., *Treatise on Crystallography*, 1839.

[848] G. Rose., *Abh. Kgl. Ak. Wiss. Berlin*, 1846.

[849] A. Bravais., *Journ. de École Polytechn*, **19** (1850), p. 1.

[850] T. von Gutzeit., *Das gesetz der Zwillingsbildungen am Stein*. Riga, 1865.

[851] L. Sohncke., *Pogg. Ann. Phys.* **32** (1867), p. 75-??.;

In 1869 Carl Klein submitted his dissertation at the University of Heidelberg. It was a comprehensive survey of the development of the concept and understanding of twinning up to that time.[852] He treats the formation of twins and distorted crystals and their relationship to the symmetry conditions of the crystal systems.

Contrary to prevailing opinion, Fredrich August Quenstedt tried to establish a new theory of twinning in crystallography. Turning against the purely geometrical approach to defining the twin elements, he did not succeed in setting up any new laws. However, he directed the attention of other researchers to the problem of twins that had been dominated by the mathematical approach.[853]

Alexander Sadebeck dedicates nearly the whole second part of its book *Angewandte Kristallographie* (Applied Crystallography) to twin formations.[854] He gives a complete list of all twins known to that time, categorizing them into the possible seven crystal systems together with their hemiedrischen forms, and thereby creates a valuable statistical work. Thus, for example, he defines the spinel law as the first twin law in the regular system as a "Twin growing together on face 411". He further notes that this law is so far only known to occur with spinel, sphalerite, and galena. In addition Sadebeck discusses again those differences, which had generally been ignored, and makes further separations of types of twins. Sadebeck's remarks are interesting to the triclinic system:

"Contrary to the twin laws of the remaining systems it is remarkable that here only normal ones of such crystal faces, which correspond to the axle levels, when Zwillingsachsen arise. The twin axles stand all in direct relationship with the crystal axes; they are partly even crystal axes, partly on the same senkrechte lines, so that one can call them right-angled substitutes of the crystal axes. These substitutes stand either perpendicularly on the axles in the axle levels, whereby each axle, since it lies in two axle levels, receives two substitutes, or they are the normal ones of the axle levels, each axle have therefore three right-angled substitutes."

Thus Sadebeck forecasts all in the triclinic system possible twin laws.

Later, considerable attention was given to twin formations by François Ernest Mallard. A convinced follower of Bravais' theories, and a lively champion of his own ideas, he was the prominent representative of the French crystallographic school during the second half of the 19th century. He classified twins and adhered to the concept of his teacher at the same time. Mallard noted that penetration twins and their formation were characteristic not only for the merohedry crystals, but were also frequently encountered in holohedral formations. He suspected that twinning played a significant role when symmetry along the axis was lacking in the lattice. In 1878 Mallard formulated this as a generalized principle, which bears his name. Working on the basis of the space grid theory, brought a new idea into the opinion of the twin problem.[855] He imagined that high-symmetrical crystals developed by twin-like grows of smaller crystal particles of low symmetry. Using the example of Leucite and Boracite he showed the fact that the cubic character of these minerals was in reality pseudocubic only which of individual lamellas of low symmetry in twin position composes itself to each other. It called this feature "isomorphic mixture that space grid" and wanted thereby all optical anomalies of the crystals to explain. It pointed the structure of the single breaking crystals to the same kind, only it took here a so fine Verzwillingung on that the lamellas can be appeared optically isotropic the total crystal compensate in their effect on the light and. With dimorphen substances it accepted the same space grid, which results in the different modifications from twin-like growing together. In this kind he explained among other things

*ibid.*, *Entwicklung einer Theorie der Kristallstruktur*. 1879.

[852] C. Klein., *Über Zwillingsverbindungen und Verzerrungen und ihre Beziehungen an den Symmetrieverhältnissen der Krystallsysteme* . Heidelberg, 1869. iv, 50 p., 3 plates.

[853] F.A. Quenstedt., *Grundriß der Kristallographie*. 1873.; *ibid.*, *Handbuch der Mineralogie*. 1877.

[854] A. Sadebeck., *Angewandte Kristallographie*. 1876.

[855] E. Mallard., *Explication des Phenomenes Optiques Anomaux Qudipre Sentent un Grand Nombre des Substances Cristallisees*, 1876.; *ibid.*, *Traite de Cristallographie Geometrique et Physique*, 1879.

the Zirkularpolarisation of the quartz and the trigonalen building of the Turmalins from triplets of rhombic rhombisch-hemiedrischer individuals.

Mallard made the error of applying his theory too far. He sought to explain all optical anomalies of naturally occurring minerals through it, including, for example, the birefringence of garnet, that are now known by later investigations to be the result of isomorphic admixture. This application of his theory created more opponents for Mallard than in reality it earned.

Returning to the works Of Mallard about twins, it is necessary to stop at its capital composition the explanation of the phenomena of the optical anomalies, observed on the large number of crystalline substances (1876 g.).[856] It was known that many crystalline formations of rhombic, monoclinic and triclinic systems in geometric sense are extremely close to the cubic, tetragonal and hexagonal crystals.

Attention is drawn to also, that such bodies frequently consist of the twinned plates, which, being repeatedly repeated, form forms with the apparent more high degree of symmetry. Investigating these formations, Mallard came to the conclusion that all optically anomalous crystals present the totality of the mixed and twinned between themselves low symmetry small plates. Those parts of crystal, in which rules one or other orienting or another of these plates, are characterized by corresponding optical properties. This conclusion used general acknowledgement. Only later was established the connection of optical anomalies with the sectorial structure of the crystals.

Gustav Tschermak tried to determine why twinning occurred.[857] He returned to the lattice theory for his answer. He knew there were three combined directions that determine the twin. Each of them has two values, positive and negative. During the normal crystallization the microscopic 'elements' of the crystal are located so that along these three directions are parallel and are characterized by identical signs. During a disrupted crystallization two adjacent 'elements' obtain different values corresponding to different directions. This will give initial stimulation to the appearance of the twin. According to Tschermak, there should be distinguished three cases of hemitropie, which are generated by twin formation:

1. Twin axis is perpendicular to possible face.
2. Twin axis is parallel to possible edge.
3. Twin axis lies in the plane of possible face and is perpendicular to edge.

Tschermak later substantially simplifies his theory, however, after he recognized that no new moment of shaping would apply to the twin crystal.[858] It calls these briefly after their contents: the surface normal law, the median Law, and the zone-axis edge normal law.

Alfred Ernest Barlow listed five packing types which he thought represented the most stable initial configurations; one of these was hexagonal close packing (1883), which he was the first to use. It is interesting to note that he employed it to explain the so-called spinel twin law by postulating a hexagonal close-packed layer joining octahedra constructed of cubic close-packed spheres. Anticipating later theories of twinning, he remarked, "The modification, as we see, involves no departure from the condition that each particle is equidistant from the twelve nearest particles." Like Wollaston, Barlow pointed out that different kinds of atoms can be represented by equal spheres of different colors, and noted that they can be present in various proportions. Later, he considered spheres of different sizes as well. Together with the chemist Pope, he gave many specific examples of such structures and constructed the corresponding crystal forms (Barlow & Pope, 1907).

Andreas Ludwig Fock raises the question about the reason of the twin formation and attempts to explain it by the influence of a preventing solvent. Twins of BaCla are supplied as his example proof, which formed in

[856] E. Mallard., *Explication des Phenomenes Optiques Anomaux Qudipre Sentent un Grand Nombre des Substances Cristallisees*, 1876.

[857] G. Tschermak., *TMPM Tschermak. Min.-Petr. Mitt.* 1880. 499.

[858] G. Tschermak., *Lehrbuch der Mineralogie*, 1897.

Gummilösung.[859]

O. Mügge wrote extensively on twinning.[860]

Theodor Liebisch draws attention to the fact that Kundt's dusting method is suitable to examine twins of badly leading crystals with polar symmetry axes and/or to identify them as such.[861]

In 1867 Fredrich Eduard Reusch discovered that some twinning was due to mechanical distortion.[862] Using the orientated pressure obtained by a knife edge he was able to create twins the rhombohedron of calcite. Heinrich Adolf Baumhauer improved on Reusch's methods, and was able to form twins in calcite through mechanical methods of any size. Baumhauer in his studies of etch figures also showed that the symmetry of the corroded figures formed on twin crystals is lower in many cases then the macro symmetry of the mineral (§8.15).[863] A full treatment of the formal crystallography of mechanical twinning was first published by Johnsen (1914).[864]

In 1899 Frédéric Félix Auguste Wallerant published a special monograph, dedicated to twins.[865] In this monograph he gives an historical survey of literature, theoretical views on twin formation, structural concepts based on Bravaian ideas, which he illustrates in lattice diagrams. His views on the subject, are now only of historical interest.

The accumulation of an enormous literature on the subject which was accumulated by the end of the 19th century, the theory of twin development for a very long time was not based strictly in mathematical expression. In 1904 a large monograph by Georges Friedel titled *Étude sur les Groupeménts Cristallins* summed up the available knowledge about twins in the period prior to X-ray crystallography. It introduced much clarity to formations of this kind and helped develop theoretical crystallography.

By special tangential coherence of individual preferential crystal faces Paul Groth tries to explain the twin accomodation, by believing, the Verzwillingung on the same cause, the Retikulardichte of the Zwülings even, leads back to be able.[866] This must have a parallelism from twin levels and cleavage planes to the consequence. During the discussion of the crystal systems and with these possible twin accommodations it repeats always again the same opinion and puts so the attempt close, the material stated by it to seize thereupon statistically.

Here all substances were ignored, with which the data not clearly or the fissileness was only indistinct. After this list one sees the fact that the view Groth's does not exist absolutely rightfully because of the 39 minerals, with which he gives exact data concerning twin and cleavage planes, has only 12 substances both levels parallel, on the other hand 27 they do not have parallel.

Stefan Kreutz, Quenstedt's pupil, gives for the first time, a short overview of the historical development of the twin research, and then examines the twin possibilities from the vantage point of the symmetry conditions created by the individual crystals.[867] He comes to the conclusion that the highly symmetrical crystals of twins is a raising of low symmetry. He then discusses the cases of

[859] A. Fock., *Einleitung in die chemische Kristallographie*. 1888.

[860] O. Mügge., "???," *Neues Jahrbuch für Mineralogie*, **1888**/1, p. 131-???.; *ibid.*, "???," *Neues Jahrbuch für Mineralogie*, **1889**/1, p. 145-???.; *ibid.*, "???," *Neues Jahrbuch für Mineralogie*, **1894**/1, p. 107-???.; *ibid.*, "Über Translationen und verwandte Erscheinungen in Krystallen," *Neues Jahrbuch für Mineralogie*, **1898**/1, p. 71-158.; *ibid.*, "???," *Fortschritte Mineralogie*, **1** (1911), p. 38-??.; *ibid.*, "???," *Zeitschrift für Krystallographie*, **75** (1930), p. 32-??.; *ibid.*, "???," *Zeitschrift für Krystallographie*, **82** (1932), p. 59-??.

[861] T. Liebisch., *Physikalische Kristallographie*. 1891.

[862] F.E. Reusch., "Synthetik Darstellung der Lehre von der Brechnung und Farbenzerster der Lichts," *Annalen der Physik (Poggendorff)*, **117** (1862), 22 p.

[863] H. Baumhauer., *Die Resultate der Ätzmethode in der kristallographischen Forschung*. 1894.

[864] A. Johnsen., 1907, Neues Jb. Mineralogie, Beilageband, 23, 237; *ibid.*, 1914 a, Jahrbuch der Radioaktivität, etc., 226; *ibid.*, 1914 b, Neues Jb. Mineralogie, Beilageband, 39, 500; *ibid.*, 1916 a, Zentralblatt Mineralogie, 121; *ibid.*, 1916 b, 385; *ibid.*, 1917, 433.

[865] F.F.A. Wallerant., *Groupements Cristallins*, 1899.

[866] P. Groth., *Physikalische Kristallographie*, 1905, p. 345.

[867] S. Kreutz., *Denkschr. math. naturw. Kl. Kais. Ak. d. Wiss. Wissen.*, 20. 1906. 1.

twin possibilities with in the individual crystal systems, with parallel and crossed twin axes.

The study of twinned crystals has gone through a similar evolution. Georges Friedel (1926) forcefully argued against the classification of twins by twin law alone, as was popular in Germany in the period following Weiss and Mohs and throughout the 19th century. Generalizing the work of Haüy, Bravais and Mallard, Friedel proposed a more fundamental classification based on the orientations of the lattices of the twinned individuals. Friedel's theory, long unnoticed, is now widely accepted, being well suited to the needs of X-ray crystallographers.[868]

Subsequent studies of twin structure were, like Barlow's theory of twinning in spinel (1883), concerned with the plausible structure of the transition layer in so-called contact twins. The individuals in a contact twin appear to lie on opposite sides of a plane; the configuration suggests that twinning originated with their accidental juxtaposition along this plane sometime during the course of growth. Experimental and theoretical studies supported this hypothesis and it was widely assumed that most, if not all, growth twins originate in this way (see the lengthy review of Cahn (1954). In an attempt to correlate this theory of twinning with Friedel's classification scheme, Schaake (1938) introduced the hypothesis of an initial composition plane, on which twinning was supposed to originate. This notion was popular for a time, but more recently the question has been raised of whether the symmetry relations assumed to exist across a composition plane (Holser, 1958) can actually be achieved in the course of growth under real conditions.

Mineralogists used to think that all twins were hemitropic, i.e., that they were composed of two halves of the same crystal turned partly around. In reality, twins have a typical structure of their own. The theory of twins, which was alluded to by Haüy and stated for particular cases by Bravais, E. Mallard, and F. Wallerant, was given its general formulation by G. Friedel in 1904.

Baumhauer conducted further studies bringing attention to the artificial twinning of Iceland spar. Attention may be drawn to the explanation given of H. Baumhauer's discovery of the artificial twinning1 of Iceland spar by means of a knife in §§ 58-61. The structure of Iceland spar is here built up as suggested by Huyghens of oblate ellipsoids of revolution, and the twinning is described on either of two hypotheses by aid of the turning and sliding of these oblates, accompanied by a shrinkage and an elongation of their figures. The explanation is thus based on a geometrical change in certain rather artificial elements of which Iceland spar is assumed to be built up, and it presents to my mind the old difficulty as to what is the exact physical equivalent of these closely packed geometrical globes and ellipsoids.

An excellent historical review of the stormy debates among crystallographers as to the correct formal description of twins was collected together by M. Löffler, in his paper on the structural and crystall-chemical foundations of twinning.[869] Later, a comprehensive survey of twinned crystals was published in 1954 by R.W. Cahn,[870] and a study of the symmetry of crystalline structure to twinning by W.T. Holser.[871]

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1864 Friedrich Scharff., "Ueber den Zwillingsbau des Quarzes," *Neues Jahrbuch für Mineralogie*, **1864**, p. 530-564.

1869 A. Sadebeck., "Allgemeines Gesetz fur tetraëdrische Zwillingsbildung," *Deutsch. Geol. Gesell. Zeitschr.*, **21** (1869), p. 640-643; Halle, *Zeitschr, Gesammt. Naturwiss.*, **34** (1869), p. 240-242.

1869 Gerhard vom Rath., "Ueber die Zwillingsbildungen des Anorthits vom Vesuv," *Annal. Phys. Chem.*, **138** (1869), p. 449-464.

1870 Friedrich Scharff., "Ueber den Einfluss des Zwillingsbaues auf die Gestaltung der Crystalle des Kalkspaths," *Neues Jahrbuch für Mineralogie*, **1870**, p. 542-558.

1871 Albrecht Schrauf., "Mineralogische Beobachtungen. Zwillingscrystalle von Gyps; neue Flächen am Argentit," *Wien, Akad. Sitzungsb.*, **63** (1871), p. 157-167.

[868] G. Friedel., *Lecons de Cristallographie.* 1926.

[869] M. Löffler., "Strukturelle und kristallochemische Grundlagen der Zwillingsbildung," *Neues Jahrbuch für Mineralogie*, Abteil A, **68** (1934), p. 125-193.

[870] R.W. Cahn., "Twinned crystals," *Advances in Physics*, **3** (1954), no. 12, p. 202-445.

[871] W.T. Holser., "The relation of structure to symmetry in twinning," *Zeitscrift fur Kristallographie*, **110** (1958), p. 249-265.

1908 V.I. Vernadsky., "Beiträge zur Energetik der Krystalle," *Zeitschrift für Kristallographie*, **1908**, p. 126-142. [Reviews all the aspects of the crystallization process, including twin formation.].
1934 M. Löffler., "Strukturelle und kristallochemische Grundlagen der Zwillingsbildung," *Neues Jahrbuch für Mineralogie*, Abteil A, **68** (1934), p. 125-193.
1954 R.W. Cahn., "Twinned crystals," *Advances in Physics*, **3** (1954), no. 12, p. 202-445..
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### 8.1.6 Epitaxial Crystal Growth[872]

From the beginnings of mineralogical studies there were frequently encountered specimens in which the crystals of one species crystallized in constant orientation with respect to the crystals of another mineral. It is a phenomenon that mineralogists originally thought indicated a form of mutual attraction between the species and in their descriptions they regularly placed these crystal groupings as a variety or type of the species. But as experimental research into mineralogical science developed, a series of artificial phenomena were discovered that were also characterized by constant crystal orientation. Thus, for example, it was observed that the crystals of certain ferromagnetic salts settle in a given orientation when they crystallize inside a sufficiently intense magnetic field. However, it was not until well into the 20th century that enough observational information had been accumulated on orientated crystal formations that the term epitaxy (or "ordered on" from the Greek words επι=on and ταξισ=in order) was invented to describe material of this type.[873]

The phenomenon of epitaxy was recognized for a long time before it was understood and many times observations appear in the earlier mineralogical works that would now clearly be called epitaxial formations. Nevertheless epitaxy was not the subject of any primary study until the 19th century and the question of its history is reduced to a very little thing. Interestingly the discovery of the phenomena occurred when researchers experimented with the crystallization of various salt solutions on the faces of natural minerals. Thus Karl Wackernagel [1800-1877] described tests undertaken in this direction around 1825.[874] Moritz Ludwig Frankenheim [1801-1869] in 1836 was the first in a long line of crystal experimentalists to grow epitaxial layers. He found that sodium nitrate grew from solution in an oriented direction on the surface of freshly cleaved calcite crystals and that the cubic crystals of potassium iodide are orientated on the cleavage plate of mica.[875] These early works of the laboratory observeration of epitaxy were limited to rare, random experiments, and contributed very little to enrich the knowledge of this subject; however, the discovery gave birth subsequently to an abundant literature on epitaxy, which has been used as a foundation to successfully develop important modern applications of its principles (i.e., microprocessors).

It was through the study of the natural crystals that the vast majority of examples of epitaxy were observed, and it was through them that ideas to how they formed were developed. Specimens of crystal overgrowth are either fully described or simply mentioned as additional information in the description of the individual

[872] Other historical information may be found in: L. Csepregi, J. Gyulai, S.S. Lau., "The early history of solid phase epitaxial growth," *Materials Chemistry and Physics*, **46** (1996), p. 178-180. • D.W. Pashley., "A historical review of epitaxy" (pp. 3-45) in: J.W. Matthews, ed., *Epitaxial growth*, part A. New York, Academic Press, 1975. [Contains informtion on modern uses rather than mineralogical studies.] • L. Royer., "Recherches expérimentales sur l'épitaxie ou orientation mutuelle de cristaux d'espèces différentes," *Bulletin de la Société Française de Minéralogie*, **51** (1928), p. 7-159. [Contains a long historical section at the beginning of the article.] • W.A. Wooster., "Brief history of physical crystallography" (pp. 61-76), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

[873] L. Royer., "Recherches expérimentales sur l'épitaxie ou orientation mutuelle de cristaux d'espèces différentes," *Bulletin de la Société Française de Minéralogie*, **51** (1928), p. 7-159. [He proposed the term epitaxy.]

[874] K.E.P. Wackernagel., "Ueber den Wirkungskreis der Crystalle," *Archiv für die gesamte Naturlehre* (Kastners), **5** (1825), p. 293-314.

[875] M.L. Frankenheim., "Ueber die Verbindung verschiedenartiger Krystalle," *Annalen der Physik*, **37** (1836), p. 516-522. [Contains the first description of epitaxial formations in crystallography.] • Shafranovskii, *Istoriia kristallografii XIX vek*, 1980, p. 139.

species. For example, Johann August Friedrich Breithaupt who is memorable as the author of many original observations, repeatedly described the regular combinations of different minerals now refered to as epitaxy in his many mineralogical works.[876]

Alexander Sadebeck [1843-1879] was apparently the first author to gather the observations dispersed in the various publications together and propose the cause of the epitaxical deposits encountered during mineralogical studies. In 1878 he describes a score of epitaxial groupings and proposes a law that in his opinion governs their development.[877] Sadebeck's law may be summarized in the following way: In epitaxy material crystallographic axes play the essential part. It always occurs that one or more crystallographic axes have a common direction in the two minerals. This concept of crystallographic axis had been introduced in to mineralogy by Christian Samuel Weiss following purely geometrical considerations. However, Sadebeck concluded that these same axes that were convenient to the study of crystal morphology also governed the law of epitaxy, because their orientation was frequently in alignment. He therefore concluded that the axes played a physical role of the first order in defining if and how epitaxial orientation forms.

In 1902, Frédéric Wallerant [1858-1936] extended the ideas of Sadebeck by taking up the study of epitaxy with a gereralized study of about fifty examples.[878] In this paper, richly illustrated with drawings of the epitaxial crystals, he deduces that the law of association may be expressed as follows: "the crystals are orientated so that at least two elements of the primitive form of the one coincide with two elements of the primitive form of the other". By "element" of the primitive form he indicates either the edges, the diagonals and the the diagonals of the faces of the primitive form. But so that Wallerant might apply his law to all the observered forms he finds it neccessary in some cases to add elements indicating the axes of the trapezohedron, which should have suggested to this emminent crystallographer that his law was not correct.

Johannes Otto Mügge [1858-1932] summarized in 1903 in a very complete article the observations made until his time on more than 70 examples of epitaxy and tried to deduce from them the factors which occur to determine the orientation of one of the crystals compared to the other.[879] The last pages of this weighty review are devoted to a discussion of the geometric relations of the regular intergrowths. Unlike preceding researchers, Mügge attaches less importance to the coincidence of axes and elements of symmetry in the two crystals. For him the essence of the epitaxy is especially the presence in the two species of one or several crystal faces having very nearly identical angles. The epitaxy of the two crystals is then formed so that these faces are parallel even if the strick elements of symmetry do not coincide in the two species. From this foundation Mügge theorized that the epitaxial formation must almost always be related to the presence of atoms or groups of identical atoms structures between the two species.

In 1906 Thomas Vipond Barker [1881-1931] extended the earlier experimental work by performing a series of systematic investigations in which a number of related structures were grown upon each other. His method consisted of placing a drop of saturated solution of alkalides onto a cleaved surface and observing the nucleation of crystalline structure through a microscope.[880] In 1908 he extended his earlier work with a series

[876] Shafranovskii, *Istoriia kristallografii XIX vek*, 1980, p. 44.

[877] A. Sadebeck., "Ueber die Krystallisation des Markasits und seine regelmässigen Verwachsungen mit Eisenkies," *Annalen der Physik, Ergangzungsband* (Poggendorff), **8** (1878), p. 625-663.

[878] F. Wallerant, "Sur les groupements de cristaux d'espèces différentes," *Bulletin de la Société Française de Minéralogie*, **25** (1902), p. 180-222.

[879] J.O. Mügge., "Die regelmässigen Verwachsungen von Mineralien verschiedener Art," *Neues Jahrbuch für Mineralogie*, **16** (1903), p. 335-447.

[880] T.V. Barker., "Contributions to the theory of isomorphism based on experiments on the regular growths of crystals of one substance on those of another," *London, Journal of the Chemical Society*, **89** (1906), p. 1120-1158. • *ibid.*, "On the regular growth of soluble salts on each other," *Mineralogical Magazine*, **14** (1907), p. 235-257.

of systematic experiments in which a number of related structures were grown upon each other. His published work is rich in results, which allowed him to make many predictions about the internal structure of the crystals that was only later confirmed through X-ray analysis.[881] His idea in the pre-X-ray period was that the study of epitaxy could provide evidence of relations with in the atomic structures of the two species.

Georges Friedel [1865-1933] adopted and widened Barker's study in 1911.[882] Following his studies on twins, Friedel showed that epitaxy occurs when a simple or complex lattice of the one of the two species has a form similar in form and volume to the lattice of the other. He goes even further and suggests that dense reticular grids are an outgrowth of epitaxy.

Such was the state before radiological studies of crystals came into widespread use after the discovery of their diffraction of X-rays. This added deeply to the clarification of how cystalline structures are arranged, and in the case of epitaxy, how the two species are aligned at the atomic level. In 1928 Louis Royer [1895-1980][883] presents a comprehensive study of epitaxy in which he gives a description of his experimental methods. Working with the aid of the newly discovered X-ray diffraction analysis of structures, he greatly increased the scope of studies of the epitaxial layers. He gives results about the epitaxy of crystals of the same symmetry and crystal structure, different symmetries but common structure and different symmetry and different structure. Royer than deduces his own law for epitaxy based upon his experimental observations, of which the most important feature is that oriented growth occurs only when it involves the parallelism of two lattice planes which have lattice networks of identical or quasi-identical form and closely similar spacings. He also gives a list of the natural epitaxial groups he has examined.[884]

Epitaxial crystallizations are within modern technology some of the most important tools. For example, the fastest microprocessors, made with compounds of the element gallium, are manufactured by epitaxial crystallizing the material onto the foundation.

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1836 M.L. Frankenheim., "Ueber die Verbindung verschiedenartiger Krystalle," *Annalen der Physik*, **37** (1836), p. 516-522. [Contains the first description of epitaxial formations in crystallography.].

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1933 G.I. Finch and A.G. Quarrell., "The structure of magnesium, zinc and aluminum films," *Proceedings of the Royal Society of London, Series A.*, **141** (1933), p. 398-414.

1956 A.R. Deo, G.I. Finch, and M. K. Gharpurey., "On the Nature of Epitaxial Crystal Growth," *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences*, **236** (1956), no. 1204, p. 7-9.

1956 D.W. Pashley., "The study of epitaxy in thin surface films," *Advances in Physics*, **5** (April, 1956), p. 173-240.

1993 Scheel, H.J., "Historical Introduction, Chapter 1" (**1**, pp. 1-48) in: D.T.J. Hurle, ed., *Handbook of Crystal Growth*. Amsterdam, Elsevier, 1993.

2002 Jan H. Van Der Merwe., "Misfit dislocations in epitaxy," *Metallurgical and Materials Transactions A*, **33** (2002), no. 8, p. 2475-2483.

2004 Marian Augustyn Herman, Helmut Sitter, and Wolfgang Richter., *Epitaxy: Physical principles and technical implementation*. Berlin; New York, Springer, c2004. xv, 522 p., illus.


## 8.2 Crystal Structure[885]

[881] T.V. Barker., "Untersuchungen über regelmässige Verwachsungen," *Zeitschrift für Kristallographie*, **45** (1908), p. 1-59, 3 plates.

[882] G. Friedel., *Leçons de Cristallographie*. Paris, 1911, p. 267.

[883] Royer was a professor of mineralogy and crystallography attached to the faculty of the University of Algers. *Cf.* Poggendorff, **6**, p. 2233.

[884] L. Royer., "Recherches expérimentales sur l'épitaxie ou orientation mutuelle de cristaux d'espèces différentes," *Bulletin de la Société Française de Minéralogie*, **51** (1928), p. 7-159.

[885] Other historical information may be found in: W. Barlow and H. Miers., "The structure of crystals" (pp. 297-337) in: *Report of the Meeting of the British Association for the Advancement of Science*, 71st Meeting, London, 1901. • Johann J. Burckhardt., *Die Symmetrie der Kristalle. Von René-Just Haüy zur kristallographischen Schule in Zürich*. Mit einem Beitrag von Erhard Scholz. Basel, Boston & Berlin, Birkhäuser Verlag, 1988. 195, [1] p., 65 illus., indexes. • M. Senechal., "Brief history of geometrical crystallography" (pp. 43-60), in: J. Lima-de-Faria, ed., *Historical atlas of crystallography*. New York, Elsevier, 1990.

Intimately intertwinned to the physical forms of crystals observed in specimens are their internal structure, or the atomic arrangement of the chemical molecules that combine to form macroscopic crystals. A crystal is not a mere geometrical abstraction. Rather a crystal's physical shape is a reflection of its interior structure. Hypotheses about the structure of crystals were, therefore, also hypotheses about the internal arrangement of the atoms, and thus closely related to the problem of the structure of matter.

### 8.2.1 Early Theories about Structure[886]

The early atomic theories did not provide useful hypotheses about the forms of crystals. Aristotle refuted Plato's connection of four regular solids with the four elements, earth, air, fire and water. He pointed out that Plato's theory required that groupings of these polyhedra must fill space, because if the particles of a substance do not completely fill the space occupied by it, then there are voids, which contradicted Aristotle's theory that a vacuum cannot exist in nature. In fact, of the five regular solids the ancient philosophers associated with nature, only the cube fills space.

In 1611 there appeared what is generally considered to be the first treatise on geometrical crystallography. It was authored by Johannes Kepler [1571-1630] under the title *Strena Seu de Nive Sexangula* (A New Year's Gift or the Six-Cornered Snowflake).[887] In it, Kepler raised the question of why snowflakes always have six corners, never three, four, five, or seven. Theorizing that the snow crystals are built from minute spheres of ice, Kepler analysises how these tiny spheres can be stacked together to form the larger crystals. His discussion leads him to describe simple cubic packing, face- and body-centred cubic packings, and simple hexagonal packing, and from these ideas he deduces the forms of the polyhedra that would arise by compressing some of these arrangements of spheres. However, he ultimately fails in this interesting discussion to explain the shapes of snowflakes based purely on geometry.

Modelling crystal structures as packings of tiny spheres is one of several representation that continued to be useful. René Descartes [1596-1650], too, used the idea of spherical particles to account for the shape of snowflakes.[888] In keeping with his mechanistic ideas, Descartes explained that the wind was the force that arranged the particles of the snowflake, and heat served to convert the equal round spheres of ice into miniature stars. Erasmus Bartholinus [1625-1698] dissertation on the shape of snow crystals also speculates on their internal structure. Published in 1661, the *De Figura Nivis Dissertatio*[889] modelled the internal structure of snow with tiny spheres. Bartholin reapplied this model when he presented his discussion of iceland spar in his much more famous, *Experimenta Crystalli Islandici Disdiaclastici* (1669).

The first scientist to consider the tiny spheres used in modeling to actually be the ultimate particles of matter, equivalent to atoms, was Robert Hooke [1635-1703]. He was also among the first researchers to consider the structure of crystals as a general problem. In his famous *Micrographia* published in 1665, he argued that all crystalline forms could be built from a few basic packing arrangements

[886] Other historical information may be found in: John G. Burke., "Chapter II. Early Theories of Crystal Structure" (pp. 10-51) in: John G. Burke., *Origins of the science of crystals*. Berkeley and Los Angeles, University of California Press, 1966. • R. Hooykaas., "The experimental origin of chemical atomic and molecular theory before Boyle," *Chymia*, **2** (1949), p. 65-80. • *ibid.*, "Kristalstreping en kristalstructuur," *Chemisch Weekblad*, **47** (1951), p. 1-7.

[887] J. Kepler., *Strena Seu de Nive Sexangula*. Francofurti ad Monvem, 1611. 24 p. English translation, *The Six-Cornered Snowflake*. Oxford, At the Clarendon Press, 1966. xvi, 74, [2] p., illus. [Annotated translation of the 1611 edition, with a long introduction giving details of the history of this work.]

[888] R. Descartes., *Les Météores*. Published with his *Discours de la Méthode*. Leiden, 1637.; Charles Adam and Paul Tannery, eds., *Œuvres de Descartes*. Paris, 1897-1913. 12 vols. **6**, p. 288.

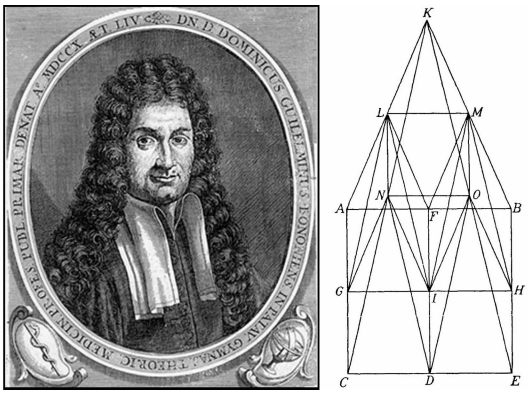
[889] E. Bartholinus., *De Figura Nivis Dissertatio*. Hafniae, 1661. [6], 42 p., one plate. [This work has sometimes incorrectly been called the earliest treatise on crystallography, because it precedes Boyles work on gems by eleven years. However, Kepler's *Sterna Seu De Nive Sexangula* (1611), which also discusses the shape of snow crystals, is much earlier still.]

of spherical atoms.[890] He then goes on to describe and illustrate how various polygonal and polyhedral figures could be constructed. Christian Huyghens [1629-1695] in a similar fashion postulated in 1690 that ellipsoidal atoms contributed to the cleavage of calcite.[891]

Critisims to assuming tiny spheres were the ultimate particle of crystals developed. For example, the assumption that atoms were all the same made it difficult to explain how chemical and textural differences arose among crystals. There was also the problem of what filled the gaps left between the spheres when they were packed together. Both Hooke and Huyghens supposed these gaps were filled with some material that was yet to be discovered.

To counter these objections alternative hypothesis of the internal structure of crystals were developed in which polyhedra of various sizes and shapes were combined together. These theories developed from microscopic studies of crystals, and its chief selling point was that the shapes filled space more effectively than spheres. However, supporters of the theory of polyhedral particles did not always assume the crystals were absolutely solid. Robert Boyle [1627-1691], who believed that the corpuscles of crystals had "exquisite shapes," credited the physical properties of crystals to some sort of porousness (1666).[892]

The first detailed geometrical theory of crystal structure to be published was given by Domenico Guglielmini [1655-1710] in his *Riflessioni Filosofiche Dedotte dalle Figure de' Sali* of 1688.[893] It describes several experiments in the precipitation of crystals from various saline solutions. Careful study of the resulting specimens led Gugliemini to conclude that only four primary crystal shapes existed, and that all other geometries observed arose from various internal combinations of




Guglielmini

these four basic shapes and their associated salt. The four salts that possessed these forms were common salt (the cube), salt of vitriol (the rhombohedron), niter (the hexagonal prism), and alum (the octahedron). The author further hypothesized that although endowed with unalterable shapes, these four base types were built from collections of very small, unseeable pieces of the named salt.[894] In 1705 Guglielmini extended his original ideas by developing them mathematically based on his observations of the physical crystals.[895] He distinguished secondary forms of the basic geometric shapes and speaks of the constant shape of the crystal forms among the same species. In this work, Guglielmini also appears to anticipate the theories of Bergman and Haüy by recognizing that there is a tiny crystal molecule that formed the nucleus inside the crystal.

By the 18th century, other theoretical directions developed. Dortous de Mairan [1678-1771] in his *Dissertation sur la Glacé* (1716) speculated that salt, pyrites, and snow were formed from needleshaped molecules.[896] The Swiss geologist Louis Bourguet [1678-

[890] R. Hooke., *Micrographia*. London, 1665. [36], 246, [10] p., 38 plates.

[891] C. Huyghens., *Traité de la Lumière*. Lugduni Batavorum, 1690. [8], 180 p.

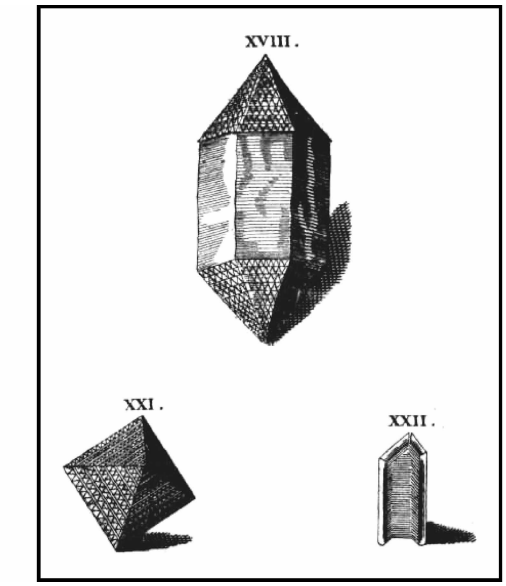
[892] R. Boyle., *Origine of Formes and Qualities According to the Corpuscular Philosophy*. London, 1666.

[893] D. Guglielmini., *Riflessioni Filosofiche Dedotte dalle Figure de' Sali*. Pisa, 1688. [4], 39, [1] p., one plate.

[894] K. Mieleitner., "Die Anfange der Theorien über die Struktur der Kristalle. Domenico Guglielminis Philosophische Betrachtungen, abgeleitet von den Formen der Salze," *Fortschritte der Mineralogie*, **8** (1923), p. 55-90.

[895] D. Guglielmini., *De Salibus Dissertatio Epistolaris Physico-Medico-Mechanica*. Venetiis, 1705. [16], 280 p.

[896] Dortous de Mairan., *Dissertation sur la Glacé ou Explication Physique de la Formation de la Glacé et de ses divers Phénomènes*. Paris, 1716. • R. Hooykaas., "Kristalstreping en kristalstructuur," *Chemisch Weekblad*, **47** (1951), p. 1-7.




Bourguet's Crystal Structure (1723)

1742] in a letter dated 12 February 1723 sent to Johann Jakob Scheuchzer expressed his opinion that rock crystal and nitre are composed from tiny triangles.[897] Having observed that some crystals of quartz show equalateral triangular depressions in their terminations, he concludes that rock crystal is formed from the build up of these microscopic particles. His ideas show a strong influence from the ideas of Gugtielmini.

By the mid-18th century, a number of theoretical advances developed chiefly associated around the ideas of Rudjer G. Bošković (Boscovich) [1711-1787]. In his *Philosophiae Naturalis Theoria* of 1758 he gave a theoretical model that replaced the atoms of a crystal with a discrete set of points, or poles, that were balanced by attractive and repulsive forces.[898] In this arrangement, each point 'occupies' space and therefore from a geometric viewpoint, his theory was compatible with the two already mentioned, while it avoided several of the pitfalls, especially the filling of space.

The multi-faceted Russian genius Mikail Vasilievich Lomonosov [1711-1765] studied crystal form, interfacial angles, and speculated on their interior structure. Using atoms of a spherical form, Lomonosov drew many figures, similar to Hooke's, to illustrate and explain the structure and crystal morphology of saltpeter.[899] His research lead him to rediscover the cubic close-packing and simple cubic packing of spheres. Unfortunately for the history of crystallography, Lomonosov's work remained virtually unknown outside of Russia until the 20th century.[900]

The word *crystallography* was introduced by Maurice Anton Cappeller [1685-1769] in the title of his *Prodromus Crystallographiae de Crystallis*, which appeared in 1723.[901] By examining a great variety of inorganic substances, sometimes even employing a magnifying glass, Cappeller concluded that a finite set of basic crystal forms existed. These he defined as the equivilent of dendritic, polyhedral, prismatic, pyramidal, rounded, cylinderical, boytroidal and crust-like. Any stone, salt, metal or earth he examined could be classified under one of these forms. Since the author also believed the manner of origin affected a substances' crystal shape, the same mineral theoretically might appear in more than one category. However, this was among the first efforts to systematize the study of crystals on the basis of crystal form. He believed that this was the initial step in determining the shapes of the particles which built the crystals.[902]

[897] L. Bourguet., *Lettres Philosophiques sur la Formation des Sels et des Crystaux et sur la Génération & le Mechanisme Organique des Plantes et des Animaux; A l'Occasion de la Pierre Belemnite et de la Pierre Lenticulaire. Avec Un Memoire sur la Theorie de la Terre.*. Amsterdam 1729. xliv, 220, [12] p., one plate. • R. Hooykaas., "Kristalstreping en kristalstructuur," *Chemisch Weekblad*, **47** (1951), p. 1-7.

[898] R.G. Bošković., *Philosophiae Naturalis Theoria redacta ad Unicam Legem Virium in Natura Existentium.* Vienna, 1758.

[899] M.V. Lomonosov., *On the Genesis and Nature of Saltpeter* (in Russian). Dissertation, Academy of Sciences, St. Petersburg, 1749.; Reprinted in: M.V. Lomonosov., *Complete Collected Works* (in Russian), Moscow and Leningrad, 1951, **2**.

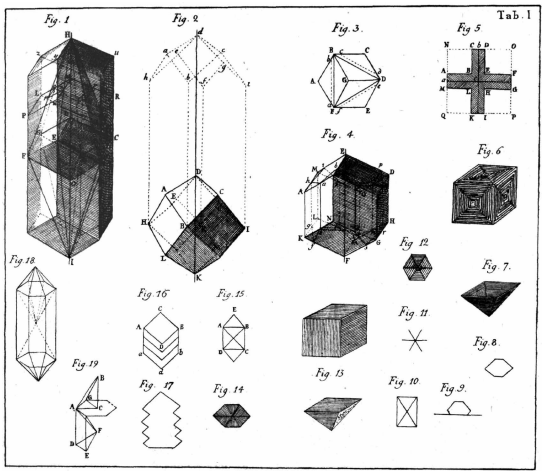
[900] Shafranovskii, *Istoriia kristallografii s drevneishikh vremen do nachala 19. stoletiia*, 1978, p. ??-??.

[901] M.A. Cappeller., *Prodromus Crystallographiae de Crystallis.* Lucernae, 1723. 43 p., 3 plates.

[902] M.A. Cappeller., *Prodromus Crystallographiae. Mit Unterstützung der Naturforschenden Gesellschaft in Luzern und anderer Schweizer Freunde der Naturwissenschaft.* Herausgegeben und übersetzt von Karl Mieleitner. München, Kunst= und Verlagsanstalt Piloty & Loehle, 1922. viii, 39, [1] p., 3 plates, 47, [1] p. [This translation contains an excellent introduction by Mieleitner that puts

In 1768, Carolus Linnaeus [1707-1778] gave his final thoughts about minerals in the twelfth edition of the *Systema Naturae.*[903] He championed a morphological approach to the study of crystals, based on their "superficial and visible structures," as opposed to physical or chemical approaches, and classified crystals into classes, orders, genera and species in a method similar to his classification of plants.[904] He apparently did not speculate about the internal arrangement of the molecules inside the crystals that he described. Instead the lasting value of his study to crystal structure research lies in his emphasis on the importance of external form, his many minute and accurate drawings of crystals, and his indication of the relations among forms through truncation. These concepts would be used by future mineralogists and crystallographers to push their own work forward.

After investigating calcite Christian F. Westfeld [1746-1823] gave the opinion that the crystals were formed from a rhombohedral shaped molecule.[905] This appears to be the first publication describing a model of a polyhedral form built from a polyhedron not identical to it in shape. Johann Gottlieb Gahn [1745-1818] who was an expert in blowpipe analysis, worked during the 1760's in the laboratory of the Swedish chemist and mineralogist Torbern Olaf Bergman [1735-1784]. Together, they investigated many minerals and crystals, and sometime during that period they discovered that when crystals of Iceland spar (calcite) were split along their cleavage planes, the resulting fragments could be further reduced to smaller and smaller rhombohedrons, suggesting that the internal structure of calcite was of that shape. Based on this observation, in 1773 Bergman transposed the concept, and published a method to construct a scalenohedron crystal of calcite from a rhombohedral 'nucleus' by the superposition of rhombic lamellae, and used it to explain the cleavage of calcite.[906] For this example, Bergman was able to show that the angle measurements of the nucleus corresponded precisely with those of the final crystal form.




Bergman's Crystal Structure (1773)

According to Bergman, the calcite nucleus was a rhombohedron. He argued that all of the many observed crystal forms of calcite could be created by superimposing layers of the rhombic lamellae on each face of the rhombohedral nucleus. Gradually, as layers were accreted, their sizes decreased according to some unknown law. Each of the various crystallized forms came about depending on the amount of decrease. Bergman, however, could not describe his law of decrement in detail, although he stated that it was the cause for the change in the appearance and number of terminal faces on a crystal. To support his this view and with the help of detailed pictures, he gave an illustration of a hexagonal prism of calcite that was formed from the build up of a rhombohedral nucleus and was terminated at each end with rhombohedral faces. He then goes on to develop two scalenohedral crystal forms by accreting layers of nuclei continually

Cappeller's work in historical perspective.]

[903] C. Linnaeus., *Systema Naturae.* Holmiae, 1768. 3 vols. [The third volume deals with mineral substances.]

[904] C. Linnaeus., *Systema Naturae.* Holmiae, 1768. **3**, p. 11.

[905] C.F. Westfeld., *Mineralogische Abhandlungen.* Göttingen, 1767, p. 50.

[906] T. Bergman., "Variae crystallorum formae a spatho orthae," *Nova Acta Regiae Soc. Sci. Upsala*, **1** (1773), p. 150-155.; English translation by Edmund Cullen contained in: T. Bergman., *Physical and Chemical Essays*, London, 1784. 3 vols.

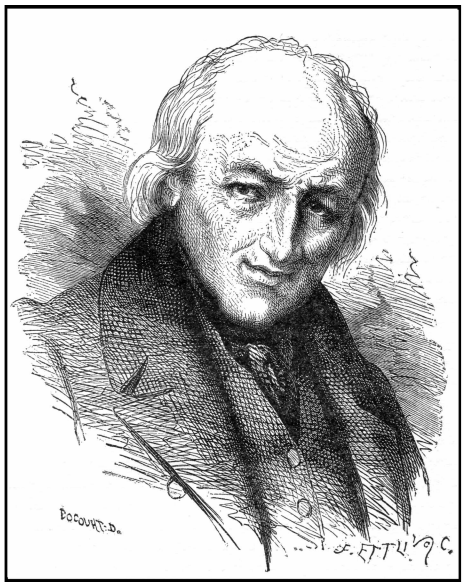
decreasing along the edges. Bergman used cleavage experiments on specimens of calcite that showed these crystal forms to support the correctness of his hypothesis.

Bergman applied his theory to other crystallized minerals, but was less successful in these other constructions, particularly the cruciform staurolite twin, built from a single polyhedral nucleus.[907] Interestingly, at that time, twinned crystals had only just been formally recognized by Rome de l'Isle as a poly-crystalline formation (see §8.3.1).[908] Bergman was not discouraged by this setback, he believed in his approach to the problem. The payoff came however not from Bergman, but through the researches of a French theologian.

### 8.2.2 Theory of Haüy[909]

Supporters of the molecular theory of crystalline matter in the late 18th century believed that crystals were composed from submicroscopic second-order particles that were chemically and morphologically identical. Although there were some researchers that thought these particles were held together by the exterior pressure of an ether, a theory of cohesion developed that insisted there was an attractive force binding the molecules together, which by 1780 had gained widespread acceptance. Such a molecular theory seemed to be supported by microscopic observations that showed even the smallest of crystalline substances had a distinct morphological shape. By the later half of the 18th century several hypothesises were put forward that said the various larger crystal forms could be built from the tiny molecules being superimposed upon one another in different configurations.

Although Jean Baptiste Louis Romé de l'Isle [1736-1790] accepted the molecular hypothesis and he insisted that all the different forms were related geometrically, he never formulated any structural theories directly.[910] He really did not dwell on the internal structure of crystals, believing that such conjectures were premature. For some of the better defined minerals, however, he poorly restated previous theories. Notably he refers to Bergman's investigations into the structure of calcite, but Romé's statements are very unsatisfactory and wavering in their support. His most important contribution to structural theory was in the law of constant interfacial angles among the sames species that he stated in its full generality in the preface to his four volume *Cristallographie* (1783). This implicitly gave a direction for further research and laid the basis for a scientific approach to structural problems.



Haüy

The science of crystals was in need of a major discovery to advance. Much groundwork had been laid by previous crystallographic

[907] R. Hooykaas., "Torbern Bergman's crystal theory," *Lychnos*, **1952**, p. 21-54. • J.A. Schufle., *Torbern Bergman. A man before his time.* Lawrence, Kansas, Coronado Press, 1985, p. 328.

[908] J.B.L. Romé de l'Isle., *Cristallographie.* Paris, 1772.

[909] Other historical information may be found in: John G. Burke., "Chapter IV. Haüy's Theory of Crystal Structure" (pp. 78-106) in: John G. Burke., *Origins of the science of crystals.* Berkeley and Los Angeles, University of California Press, 1966. • R. Hooykaas., "Les débuts de la théorie cristallographique de R.J. Haüy, d'après les documents originaux," *Revue d'Histoire Sciences*, **8** (1955), p. 319-137. • Seymour H. Mauskopf., "Crystals and compounds: molecular structure and composition in nineteenth-century French science," *Transactions of the American Philosophical Society*, **66** (1976), p. 1-82.

[910] R. Hooykaas., "De kristallografie van J.B. de Romé de l'Isle (1783)," *Chemisch Weekblad*, **47** (1951), p. 848-855. • *ibid.*, "Romé de l'Isle en de structuur theorie," *Chemisch Weekblad*, **47** (1951), p. 909-914.

studies, noteably those of Bergman and Romé de l'Isle, but it required a synthesis of what was already established to weave together an elegant, closely knit theory. This task fell to the French Abbé and mineralogist René Just Haüy [1743-1822], who as early as 1781 speculated that the internal structure of crystals was built from small polyhedral particles. In a fabled story Haüy reportedly dropped a calcite crystal which broke into several rhombohedral cleavage fragments.[911] Upon seeing this Haüy intuitively knew its importance as an experimental method to investigate the internal structure of crystals. He continued studying the cleavage phenomena in other minerals and quickly deduced that each mineral crystal had a specific and characteristic shape to its cleavage fragment regardless of the external crystal form. Haüy correctly theorized that this was an empirical method by which crystallized minerals could be studied and individual species distinguished from one another. For example the nuclei that build a scalenohedron crystal of calcite were composed of sheets of tiny rhombohedra. He was intense and focused in his investigations and with the encouragement of Daubenton, Haüy presented his first two memoirs dealing with the structure of garnet and calcite, respectively, to the Academy of Sciences on February 21[912] and December 22, 1781.[913] These papers and Haüy's continued diligent study of other crystalline substances impressed the other members of the Academy to such an extent that he was elected an associate in the botanical class on February 8, 1783.

Writing years later, Haüy declared that he was completely unaware of the similarity of his work to Bergman's previous study. He said it was only after his memoires were presented that he was introduced to the earlier work. Some historians of science have suggested, however, that Haüy was "entirely in Bergman's debt and the supposed breakage of calcite never occurred."[914] But this does not detract from Haüy's stature as the most influential pioneer of crystallography of his time. He developed the idea of a primative particle much further than Bergman ever did and accomplished what others failed to do: Namely derive laws that mathematically explained the variety of crystal forms found in the mineral kingdom.

In 1784 the first book of Haüy, *Essai d'une Théorie sur la Structure des Crystaux* was published. This work was insturmental in establishing a solid foundation on which his later theories of crystal structure rest. In it, Haüy brought together the earlier advances in crystallography made by others into a coherent structural theory, based on the structural unit, the *molecule constituante* (later renamed by him to *molecule integrante*). Haüy's conceptual model depicted crystals as built up out of these molecular units which were polyhedral in form. He also theorized a "nucleus" or "primitive form" that was common and unique among all crystals of the same mineral species. This primative form Haüy wrote was often revealed by the cleavage of a crystal symmetrically along its angles and edges. He thought these building blocks represented the crystallographic, not necessarily the chemical, primary particle. Crystals formed through the accretion of additional molecule integrantes to the primative form. Smooth crystal faces were parallel to cleavage planes, while other secondary faces are stepped, although due to their microscopic size are not visible. This is the first time Haüy presented and successfully demonstrated the underlying evidence for his later laws of decrement. He would continue to research and extend it for the remainder of his career.

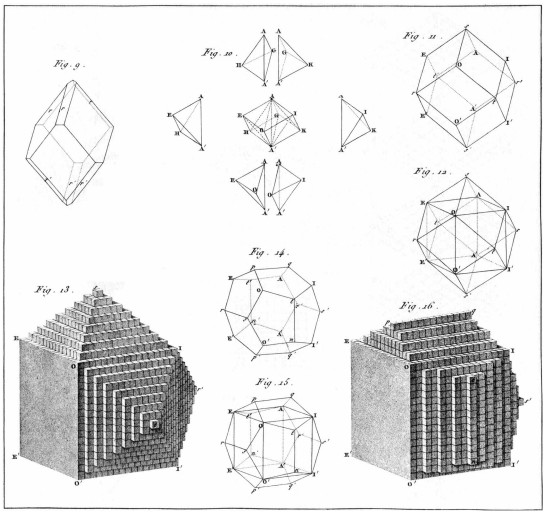
In the *Traité de Minéralogie* published in 1801, Haüy refined his empirical law of

[911] George F. Kunz., "The life and work of Haüy," *American Mineralogist*, **3** (1918), p. 61-89.; reprinted, *Bulletin of the New York Mineralogical Club*, **2** (1918), p. 61-89. • Herbert P. Whitlock., "René-Just Haüy and his influence," *American Mineralogist*, **3** (1918), p. 92-100.; reprinted, *Bulletin of the New York Mineralogical Club*, **2** (1918), p. 92-100.

[912] R.J. Haüy., "Extrait d'une mémoire sur la structure des cristaux de grenat, présenté à l'Académie royale des sciences et approuvée par cette compagnie le 21 février 1781," *Journal de Physique*, **19** (1782), p. 366-370.

[913] R.J. Haüy., "Extrait d'une mémoire sur la structure des spaths calcaires, approuvée par l'Académie royale des sciences le 22 décembre 1781," *Journal de Physique*, **20** (1782), p. 33-39.

[914] R. Hooykaas., "Torbern Bergman's crystal theory," *Lychnos*, **1952**, p. 21-54.



Haüy's Crystal Structure (1801)

a 'rise-to-run' ratio on the stepped faces of crystal presenting it as a simple ratio, p/q, where p and q are small multiples of (generally different) units of length.[915] This became his fundemental "law of decrement," restated later as the law of simple rational intercepts. It was a useful tool in his arsenal. Through it he correctly deduced that the regular dodecahedral form cannot occur in crystals. He considered the law of decrement as subserveant to the laws of symmetry, and designed symbols to designate the crystal faces, edges and vertices.

The *Traité de Minéralogie* is arguably the most influential work written in the historical development of mineralogy and crystallography. It is a work of comprehensive insight, and much of it, written in literary fluency, repays the casual curiosity of mineralogists and historians of science. Haüy's *magnum opus* containing his theory of crystal structure and his system of mineral classification that was based upon his structure theory. For this purpose Haüy believed that chemistry played a secondary rôle to crystallography in determining the groups and species of mineralogy. His meticulous attention to the forms of crystals allowed him to unite in the same species minerals that had previously been listed as separate species, such as beryl and emerald, and to distinguish a number of minerals previously lumped together, such as the "zeolites." Above all, Haüy directed attention to the internal structure of crystals and demonstrated that regularity of the external configuration was merely a manifestation of internal order.

After the publication of the *Traité de Minéralogie*, Haüy gained scientific fame throughout Europe. He carried on an active correspondence with contemporary scientists and became a member of more than twenty foreign scientific societies and academies.

It was admitted universally that Haüy had succeeded in explaining the reason for the occurrence of the variety of forms which the crystals of the same substance might take by the assumption of integrant molecules and laws of decrement which affected their superimposition on the crystal nucleus. However, not all of the models Haüy constructed using his law were equally received. For example, his construction of an octahedron from a cubic nucleus required that moleculed were added to the edges of the original lamellae juxtaposed on the cube faces while molecules were similtaneously being removed from the corners of the same lamellae. Nonetheless, Haüy's theory went a long way in explaining the complexities of crystal formation and structure. Another major impediment to Haüy's stalwart insistance that each substance had a primitive form or molecule integrant that was unique and not shared between substances. Chemical science was making important strides at the end of the 18th century, and slowly evidence accumulated that some mineral species shared identical chemistry but most definitely different crystal forms. Specimens of native sulfur were recovered that showed the mineral crystallized in both orthorhombic and monoclinic forms, pyrite (cubic) and marcasite (orthorhombic) were shown to have the same formula, $FeS_2$. But most importantly, the common mineral calcite (trigonal) had the same chemistry as aragonite (orthorhombic), namely $CaCO_3$. Haüy and his supporters took extraordinary measures trying to prove there was a significant difference in the chemistry of these minerals.

[915] Louis P. Gratacap., "Haüys Traité de Minéralogie," *American Mineralogist*, **3** (1918), p. 101-125.; reprinted, *Bulletin of the New York Mineralogical Club*, **2** (1918), p. 101-125.

The scientific journals of the period are a testament to their creative but ultimately futile efforts.

The discovery by Mitscherlich of isomorphism in 1817 and dimorphism in 1819 gave a clear explanation of why specimens of this type occurred, and it was the death knell to Haüy's definition of a mineral species as defined by the molecule integrant. Isomorphism proved that the integrant molecule of two or more compounds could be virtually the same if the number of chemically related atoms and their arrangement were identical. Similarly, dimorphism (later called a subgroup of polymorphism) showed that the same chemical compound could crystallize inat least two different forms entirely unrelated to Haüy's theory. Therefore, his insistance that crystallography take presedence above chemistry in determinative mineralogy was shown to be wrong. Yet his laws of decrement led directly to the later development of systems of crystal classification and the concept of a space or crystal lattice. It is not to much of a stretch to say all subsequent work in the field of crystal structure has been an extension or modification of his research.

### 8.2.3 Later Structural Studies[916]

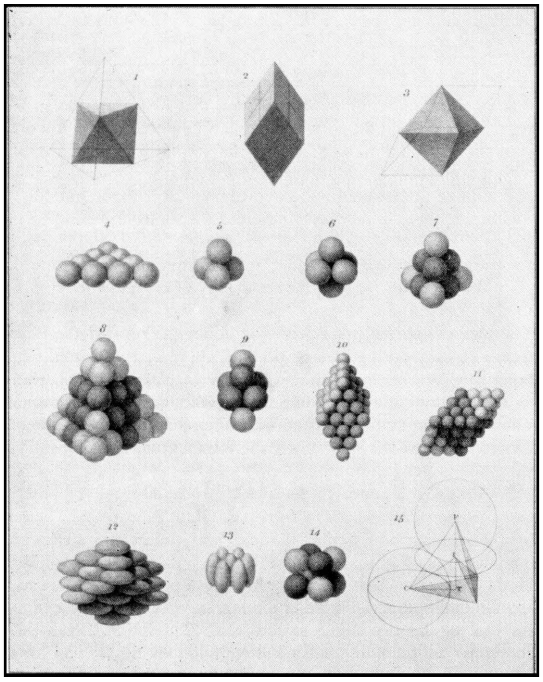
In the early 19th century, many attempts were made to construct models of the interior structure of crystals using their cleavage, external symmetry, and other directional physical properties as a guide. The work of Haüy had been influential in causing an intense interest in the subject to develop. Haüy and his students had used his theoretical model to describe the crystal structures of hundreds of minerals. But after the introduction of the reflecting goniomenter in 1809 that allowed ever increasing accuracy in angular crystal measurment to be made the harmony the French school envisioned in crystal structures came increasingly under scrutiny. The principle that the dimensional ratios of the integrant molecules must be mathematically simple and elegant were questioned more often as more accurate angular values of crystals were made and shown to be outside of the theoretical limits. Although Haüy's confidence in his theory was not shaken by this new information, other researchers began to have serious doubts about the foundations on which his theory was erected.

Another attack to Haüy's crystallographic method came from the growing challange of the new chemistry, initiated in the 1780's by Antoine Lavoisier and his colleagues. This challange arose from three important developments: (1) the discovery of new chemical elements, (2) the law of constant proportions in chemical compounds, and (3) revival of the atomic theory. Analytical chemistry had finally reached a stage where it was becoming a reliable tool to give an accurate accounting of the chemical composition of minerals. A number of previously unknown compounds were appearing in these analyses that were later discovered to be new elements. In 1806 Proust [xxxx-xxxx] made a final statement about the chemical constantancy of compounds that desisively showed that the elements within a chemical compound are always in the same proportion. Advances were also made on the theoretical level through the John Dalton's theory of atoms of different elements have different weights, and that combinations between elements occur by the union of single atoms or a multiple number of them. All of these advances began to focus attention on the French idea that every unique chemical compound had its own unique molecule integrant. However, with these discoveries mineralogists started to recognize that minerals, in particular the silicates, were much more complex chemically than anyone previously thought. Chemistry was also showing that relatively simple naturally occuring compounds such as calcium carbonate ($CaCO_3$) occurred in two minerals, calcite and aragonite, with distinctly different crystallographic structures, something

[916] Other historical information may be found in: John G. Burke., "Chapter IV. Haüy's Theory of Crystal Structure" (pp. 78-106) in: John G. Burke., *Origins of the science of crystals*. Berkeley and Los Angeles, University of California Press, 1966. • Manuel Font i Altaba., "Problemàtica historica de la cristallografia: La cristallografia Catalana del segle XIX," *Memorias de la Real Academia de Ciencias y Artes de Barcelona*, **45** (1982), p. 331-410. • A. Guinier., "La cristallographie, de Haüy jusqu'aux Bragg et à leurs successeurs," *Revue d'Histoire des Sciences et de leurs Applications*, **50** (1997), p. 295-301.

impossible under the structural theory of Haüy.

The great Swedish chemist Jöns Jakob Berzelius [xxxx-xxxx] studied chemical elements, determining their properties, and establishing their relative atomic weights and described the chemical formulas of inorganic and organic compounds. He became one of the leading figures in attacking the problem of crystal structure versus chemical composition. In fact he probably had little belief in Haüy's theory. Being a master of quantitative and qualitative analysis, Berzelius wanted to build mineralogy squarely on the foundation of chemistry. Through the work of Berzelius and his disciples the mineralogical ideas presented a major challenge to Haüy's purely crystallographic approach to the classification of minerals.



Wollaston's Crystal Structure (1813)

William Wollaston [xxxx-xxxx] proposed in 1813 a model of crystal structure that could be explained by the packings of equal spheres.[917] This idea was not new having been advanced earlier by Hooke and others, but Wollaston extended the theory. He did not address the question of whether these spheres were rigid atoms or the force fields of points, using them instead as a geometrical tool. He also suggested that crystalline compounds that had two kinds of atoms could be shown by packings of spheres of two different colors. Almost a century later, this model was reintroduced by Barlow & Pope when the were interpreting the results of X-ray diffraction patterns.

Another direction was taken by Christian Samuel Weiss [1780-1856], a professor of mineralogy in Berlin. He did not subscribe to the atomic theory, believing instead that some type of directional generating force acted upon crystals during the crystallization process. He believed that crystallographic axes had physical significance, and could be used to show structural features within the crystal, as well as be used as a basis for crystal classification.

The physicists also explored the structure of crystals. Among the first was Ludwig Seeber [1793-1855], professor of physics at Freiberg, who pointed out that Haüy's model could not explain the expansion and contraction of crystals with temperature changes. He proposed, therefore, replacing Haüy's polyhedra with tiny spherical atoms, uniformily spaced, with their centers of gravity coinciding with the centers of the molecule integrants. These atoms were placed in rows and layers, balanced by positive (attractive) and negative (repulsive) forces in a way similar to Boscovich's approach. By this method, Seeber was among the first to suggest the concept of an internal crystal lattice. Investigating problems of elasticity, two innovative French mathematicians, Claude Navier [xxxx-xxxx] and Augustin Cauchy [xxxx-xxxx] similtaneously with Seeber proposed thinking of solids as arrays of mathematical points extending symmetrically through 3-dimensional space. But at the time, these researches were largely unrecognized by most crystallographers.

In 1830, Johann Friedrich Christian Hessel [1796-1872] demonstrated through an exhaustive analysis of external crystal

[917] W.H. Wollaston., "On the elementary particles of certain crystals," *Philosophical Transactions of the Royal Society of London*, **1813**, p. 51-63. [Wollaston's illustrations of the packing of spherical particles to account for the structure of crystals. Note the different colored balls that Wollaston theorized could account for binary chemical compounds.]

symmetry the fact that there can be only 32 crystal classes and that only two-, three-, four-, and sixfold axes of symmetry can occur. These represent the present crystal classes. Hessel's results were first published in 1830, in an article entitled "Krystall" in *Gehler's physikalisches Wörterbuch* and although the article was republished separately in the following year, it received no recognition among his contemporaries.

The idea of a space filling lattice inside a crystal was proposed by other researchers. The German physicist and crystallographer Moritz Frankenheim [1801-1869] explored the idea of crystal structure in his *Die Lehre von der Cohaesion* published in Breslau in 1835. He recognized that there was a finite number of arrangements that a lattice structure of atoms could possess within a 3-dimensional space. He carried out a geometrical investigation to discover that number, he reproduces in a truncated form in his text. He concludes that 15 such lattice arrangements exist, and then discusses how these structures relate to the observed forms and cleavages of crystals. Unfortunately a mathematical error caused him to miscalculate the correct number of crystal space lattices that can exist.

In 1840, a former student of Haüy's, Gabriel Delafosse [xxxx-xxxx] argued that the molecule integrant instead of being the chemical molecule of the mineral could instead represent the space belonging to a lattice point within the structure of a crystal, or perhaps the outline of the vertices of a crystal lattice. All of these studies prefaced the further work of the structuralists.

At the same time that the concepts of the internal structure of crystal was being clarified, ideas about the symmetry and form of crystals were being investigated. Although by the mid-19$^{th}$ century most scientists had rejected the concept of the molecule integrant, Haüy's model of a crystal as a repeating array of particles was showing promise. The idea of some type of structural periodicity in crystals had been implicit in much previous crystallographic work, it was Haüy that proposed periodicity as the basic structural characteristic of all crystals.

Louis Pasteur [1822-1895] whose name is associated with so many scientific accomplishments gave some of his most profound and original contributions, which are also the least famous, to crystallography.[918] Beginning about 1847 Pasteur carried out an impressive series of investigations into the relation between optical activity, crystalline structure, and chemical composition in organic compounds, particularly tartaric and paratartaric acids.[919] This work focused attention on the relationship between optical activity and life and provided much inspiration and several of the most important techniques for an entirely new approach to the study of chemical structure and composition. In essence, Pasteur opened the way to a consideration of the disposition of atoms in space, and his early memoirs constitute founding documents of stereochemistry. However, Pasteur's discovery in 1848 of the relation between optical activity and enantiomorphic forms does not appear to have influenced contemporary theories of crystal structure.

In 1848 there began to appear a series of papers authored by Auguste Bravais [1811-1863], a French naval officer and scientist of broad interests and accomplishments. Initially they started as a mathematical exercise treating the variety of geometric forms that could exist in space built from a regularly distributed array of points in space. He then applies his mathematical investigation to crystals, viewing the points as centers of gravity for the crystal's chemical molecule or as points of electromagnetic force. With this model Bravais accurately explained the cleavage and external symmetry as a property of the recticular density of atoms inside the crystal. More importantly, however, he correctly derived through mathematics the 14 possible space lattices that differed in symmetry and geometry, where the points of the unit cell would maintain their symmetry when put through translational repetition in

[918] Shafranovskii, *Istoriia kristallografii XIX vek*, 1980, p. 180-192.

[919] Burke, *Origins of the Science of Crystals*, 1966, p. 86.

space. This was the foundation of his work in his paper "Mémoire sur les Systèmes Formés par des Points Distribués Régulièrement sur un plan ou dans l'Espace" (1850). In a clear and elegant presentation, he derives his space lattices (showing that two of Frankenheim's were identical) by showing the arrangements of rotation axes and planes of reflection in a point lattice, and showed that these structure provide an explanation for each of the seven crystal systems. The "Etudes Cristallographiques" (1851) includes Bravais' statement of of the law of rational indices, together with his interpretation of cleavage and crystal morphology. The cleavage planes of a crystal, he stated, occur where the density of lattice points is the highest (this was later called Bravais' law, or the law of reticular density). Thus Bravais was able to extend Haüy's construction of various crystal forms to a prediction of the order of their importance. According to him Merohedry (and twinning) could be explained by taking into account the symmetry of the (supposedly polyhedral) *crystallographic molecules* positioned in parallel orientation at the lattice points (see §8.3.1). After Bravais introduced his techinques into the problem of constructing a mathematical model of crystal structure the study of crystallography started to be regarded as distinct from mineralogical problems that described physical and chemical properties.

Just how the chemical atoms or molecules were arranged inside the unit cells that formed the space lattice was a a matter of speculation. However, contemporaneous with Bravais' work was early mathematical research into group theory. In fact, one of its early workers, Cauchy [xxxx-xxxx] presented Bravais' memoirs to the French Academy of Sciences, giving a report on their content. But it was another early specialist of group theory that shed light on the problem of the atomic arrangement.

In 1867 an amateur crystallographer Axel Gadolin [1828-1892] published his *Deduction of All Crystallographic Systems and their Subdivisions by means of a Single General Principle* in which he deduced the possible configurations of symmetry elements, illustrated them in stereographic projection, and listed the simple general form corresponding to each. Several of these forms had not yet been observed. Some forms assigned to different classes by Naumann were shown to be equivalent with respect to symmetry. The enumeration of the 47 simple crystal forms seems to have evolved gradually during the development of the theory of symmetry, instead of being proposed by a single individual.[920]

This happened in 1869 in the "Mémoire sur les Groupes de Mouvements" prepared by M.E. Camille Jordan [1838-1922]. In the paper Jordan considered both continuous and discrete groups of 'proper' motions of sets of points by exploring the possible combinations of rotations, screw rotations and translations.[921] His study derived 174 possible point groups, which unfortunately was incorrect, and Jordan does not discuss the applications of his work to crystallography. He may have been oblivious to them. Nevertheless, his work laid the basis for the later derivation of the space groups. Another researcher Ludwig Christian Wiener [1826-1896] first defined regularity in an arrangement of identical atoms to mean that every atom has the remaining atoms arranged about it in the same manner. In the second edition of his book *Grundzüge der Weltordnung* (Bases of World Order) (1869) Wiener emphasized the regularity in the arrangement of identical atoms is reached when each atom is surrounded in an identical way by other atoms.[922] Given this thesis he recognized that parallelism of atoms was not required, showing that that there were other possible structures not covered by Bravais. Although this became the first of a series of steps to extend the lattice theory of Bravais, Wiener does not give a complete investitgation of these structures.

At the start of his career Leonhard Sohncke [1842-1897] was interested in mathe-

[920] Shafranovskii, *Istoriia kristallografii XIX vek*, 1980, p. 125-129.

[921] Shafranovskii, *Istoriia kristallografii XIX vek*, 1980, p. 162.

[922] Shafranovskii, *Istoriia kristallografii XIX vek*, 1980, p. 162.

matics, but he turned his attention to the internal symmetry of crystals in the mid-1870s. He studied the previous work of Bravais concerning the 14 types of space lattice. The significance of Jordan's work also attracted his attention, he studied and corrected it, reinterpreting the information in terms of systems of points. It was while studying previous work in the field, that Sohncke discovered that in 1830, Hessel had derived the 14 lattice groups, and consequently Sohncke insured that a new edition of Hessel's work was published.

The 14 lattices described by Bravais described only 7 of the 32 classes of external symmetry. It was while studying the patterns of internal symmetry, that Sohncke recognized that previous investigators had viewed internal symmetry from a completely external perspective. As a condition of symmetry they had imposed a rule of translational equivalence, and Sohncke realized that this condition could not be justified. Since symmetry is described as the equivalence of internal configurations he correctly summarized that it did not matter if one's view was from outside the object or from a point inside the crystal. He insisted that the system of points representing the space lattice is the same for every point and that it need not be a parallel view.

Based on this insight, Sohncke first dervived 66 different spatial arrangements of points (now called the space groups of montions of the first order) by introducing two new elements of symmetry: the screw axis, in which a rotation about an axis is combined with a translation of the system along the axis, and the glide plane, in which the reflection in a mirror plane is combined with a similar translation without rotation along the axis. However, it was shown that two of the arrangements were equivalent, thus reducing the number to 65. This extension to Bravais' lattice theory was Sohncke's chief scientific contribution, reported in his major work, *Die Entwicklung einer Theorie der Krystallstruktur* (1879). He failed, however, to incorporate two additional symmetry elements into his study: the rotation-reflection and the rotation-inversion axes.

Inclusion of these elements by Fyodorov and almost simultaneously by Arthur Schoenflies and William Barlow in the late 1880's added the additional 165 space groups.

At an early age, Evgraf Stepanovich Fyodorov (Federov) [1853-1919] began studying geometry and symmetry. He was interested in the topological features of the convex polygons and space filling polyhedra, which served him in his professional life as professor of mineralogy and crystallography at St. Petersburg. Recognizing the need to generalize Sohncke's work, Fyodorov used a form of analytical geometry that he adapted to study regular systems of points. By introducing two new symmetry elements to his calculation, the screw axis and the glide plane, Fyodorov was led to the brilliant derivation of the 230 space groups. This was 165 more than had been previously calculated and it covered all of the symmetry groups that governed the periodic distribution within all crystalline matter. This derivation has become the foundation of contemporary mineralogy and the basis for explaining the atomic structure of minerals. The period of the first geometrical investigations and publications was crowned by the classic work *Simmetria Pravilnykh Sistem Figur* (1890), which contained the first deduction of the 230 space groups. But because his work was in Russian, it did not become generally known until after the publication in 1891 of the work of Schoenflies, who also completed the derivation of the space groups through geometrical group theory.

In 1891, shortly after the appearance of Fyodorov's work, the German mathematician Arthur Moritz Schoenflies [1853-1928] published his principal work, *Kristallsysteme und Kristallstruktur*, that contained his own derivation of the 230 space groups. In it Schoenflies also proved Fyodorov's important theorem that a group of motions in 3-dimensional space that maps a regular system of points onto itself necessarily contains a subgroup generated by three independent translations. In this way the Bravais lattices, which had a secondary role in Sohncke's work, are shown to be the foundation of all regular atomic arrangements inside crystals. Generalized systems of points were regarded as being made of 'interpenetrating identical

lattices'. Schoenflies's book became the better known work, being written in German and more readily available, but it was the continued efforts of Fyodorov that extended the research. In several articles published in the *Zeitschrift für Kristallographie*, Fyodorov compared his results to those of Schoenflies and made a series of critical corrections and notations.

Other structural results presented in Fyodorov's articles are a strict mathematical definition of thirty-two point groups for six crystallographic systems, which still retain their significance. The foundation for this classification was the idea of using a number of single and symmetrically equivalent axes in crystals. This system resulted in a new nomenclature of systems and point group symmetries, today accepted throughout the world and known as Fyodorov-Groth nomenclature. Fyodorov's group classifications are, with the aid of X-ray diffraction, at the base of modern mineralogical determinations of the atomic structure of minerals.

William Barlow [1845-1934] also derived the space groups, but he delayed publishing his list (1894).[923] Using a method based on Sohncke's, instead of systems of points, he considered geometric patterns of orientated motifs. To pursue his investigations, Barlow used pairs of gloves to model his results. However, Barlow's contribution to the theory of crystal structure outweighed his derivation of the space groups. In a series of articles he suggested that atoms inside a crystal fill distinct portions of space, and therefore, the structure of a crystal can be modeled by the packings of spheres.[924] This theory supposed that separate molecules existed inside the crystalline structure, an innovative idea for the time. Barlow lists five different configurations for his spherical packings, which he considered to be the most stable initial configurations, including the first use of the hexagonal closest packing. Using his theory, he postulated that the so-called spinel twin law could be explained by a hexagonal close-packed layer attaching octahedra built from cubic close-packed spheres. He correctly argued that this condition did not depart from the condition that each particle is equidistant from its 12 nearest neighbors. He also championed, as had Wollaston, the idea of using equal spheres of different colors to represent the different kinds of atoms. In later work, Barlow applied spheres of different sizes. Working with the chemist Pope [xxxx-xxxx] , he gave many examples of the structures and constructed their corresponding crystal forms.[925]

As convenient as the lattice theory was to the theorists, at the turn of the century, it was not universally accepted as a model of physical reality. Although it could be used to predict the behavior of some properties, many other properties of crystals could not predicted from crystal structures. Georges Friedel [1865-1933] in 1904 observed that the current structural theories of crystals presupposed the existence of two types of interactions between the particles: affinity, which binds atoms into molecules, and cohesion, which binds molecules into crystals.[926] Preferring not to consider such a distinct separation, he supposed that the interior of a crystal was essentially a heterogeneous pattern, composed of particles placed at various distances. In this instance the lattice of the crystal becomes a geometrical structure constructed around any molecule of the crystal. He also correctly recognized that at the atomic scale, different points inside the crystal structure can no longer be viewed as identical points. The law of reticular density was reexamined in the early years of the century by the French crystallographer Friedel, who showed (1907) that it correlates well with observation. As a result of this, it was accepted as generally valid, despite the fact that it could not account for merohedry and other anomalies.

In 1908 the Russian crystallographer George Wulff [1863-1925] showed that Bravais' structures predicts not only the faces which should appear on the crystal but also its polyhedral type in the sense of Fyodorov.[927] For if it is assumed that the rate of growth of

[923] W. Barlow., *???????*. 1894.

[924] W. Barlow., "??????????," *Nature*, **??** (1883), p. ??-??.

[925] Barlow & Pope., "?????," *??????*, **??** (1907), p. ??-??.

[926] G. Friedel., *??????*. Paris, 1904.

[927] G. Wulff., "??????," *??????*, **??** (1908), p. ??-??.

a crystal in the direction normal to a crystal face is inversely proportional to the reticular density of that face, then it follows that the shape of the crystal is that of the Dirichlet region of a point of its polar lattice, and hence is a parallelohedron.

In 1909, Madelung [xxxx-xxxx] established a classical theory of ionic crystals. He theorized that crystals were compposed of positively charged metal ions and negatively charged nonmetallic ions.[928] The electrostatic attraction between the oppositely charged ions was assumed to be balanced by the repulsion of the ions when they were a specific distance apart. Interaction between the electronic shells surrounding the atomic nucleus caused the replusion between the ions. As a theory it had considerable success in giving values of the cohesive energies of the alkali halides.

Max Born [xxxx-xxxx] and Karman [xxxx-xxxx] in 1912 published a paper, "??????????????" (On Vibrations in Space Lattices) that marked a turnign point in the theories of solid state.[929] Born followed this with a book, *Atomtheorie des festen Zustandes (Dynamik der Kristallgitter)*, which applied quantum theory to the vibrations of atoms, arranged in crystal lattices.[930] This treatment gives a theory of characteristic properties of specific heat of crystals, as a function of temperature, thermal expansion and a number of other properties.

Even though important mathematical advances drove the theory of crystal structure to great heights, there was little assumption that actual measurements of the atoms, ions, or molecules in crystals could ever be made. But the discovery in 1912 of X-ray diffraction gave direct evidence showing the arrangement of atoms inside a crystal.

## 8.3 X-Ray Crystallography[931]

In the late 19th century physicists were experimenting to unravel the mysteries of matter, particularly the atom. Using discharge tubes that generated a large voltages of electrical charge, the electron was one of the first particles they discovered. X-rays were another outgrowth of the operation of discharge tubes. In 1895 Wilhelm Conrad Röntgen [xxxx-xxxx] , a professor of physics at Wurtzburg, was studying the emission of ultraviolet light by discharge tubes, using as a detector, crystals of barium tetracyano platinate ($BaPt(CN)_4$), which fluoresce under ultraviolet light. One day he noticed that the crystals fluoresced a considerable distance away from the tube, even though the tube was shielded by a black paper wrapper. Röntgen observed that the radiation that caused fluorescence on a screen several feet away, was originating from the glass at the end of the discharge tube where the cathode ray beam struck.

Designating his discovery as X-rays, Röntgen studied the effect of beam as it passed through various substances. He noted that generally the beam was absorbed by dense and thick materials, while less dense and thin material allowed the energy to pass through. Importantly, he found that bones were opaque to the radiation, while the surrounding soft tissue of a body transmitted the radiation readily. He also discovered that covered photographic plates, when struck by X-rays, would act as if they were exposed, allowing

[928] Madelung, 1909.

[929] M. Born and Karman, 1912

[930] M. Born., *Atomtheorie des festen Zustandes (Dynamik der Kristallgitter)*. Leipzig, 1923.

[931] Other historical information may be found in: P.P. Ewald, ed., *Fifty years of X-ray diffraction. Dedicated to the International Union of Crystallography on the occasion of the commemoration meeting in Munich, July 1962.* Utrech, The Netherlands, N.V.A. Oosthoek's Uitgeversmaatschappij, 1962. ix, [1], 733 p., illus., indexes. [Contains numerous papers, outlining the history of the first 50 years of X-ray diffraction.] • P. Forman., "The discovery of the diffraction of X-rays by crystals: A critique of the myths," *Archive for History of Exact Sciences*, **6** (1969), p. 38-71. • J.C. Speakman., "The discovery of X-ray diffraction by crystals," *Journal of Chemical Education*, **57** (1980), 489-90. [Notes: An account of the crucial crystallographic experiment suggested by Max von Laue and performed by Friedrich and Knipping in Munich in 1912, including a brief critique of Paul Forman's 1969 paper "The discovery of the diffraction of X-rays by crystals: A critique of the myth", and P. P. Ewald's response to it.] • K.H. Widerkehr., "Über die Entdeckung der Röntgenstrahlinterferenzen durch Laue und die Bestätigung der Kristallgittertheorie," *Gesnerus: Revue Trimestrielle publiée par la Société d'Histoire de la Médecine et des Sciences Naturelles*, **38** (1981), p. 347-369.

for the image to be captured photographically. Medical professionals began using X-rays a few months after the announcement of their discovery.

In 1912, Max von Laue [xxxx-xxxx] , in response to a question proposed by P. Ewald [xxxx-xxxx] , suggested an experiment that suggested the atomic spacing of the planes in ionic crystals was the same order of magnitude as the wavelengths of X-rays. In this instance, Von Laue suggested that the atomic structure of the crystal would behave towards X-rays much as a grating behaves towards light; both cause interference phenomena and produce diffraction patterns. Two of Von Laue's assistants set up the experiment. They passed a fine beam of X-rays through a crystal and allowed it to fall on a photographic plate behind the crystal. When the plate was later developed there appeared a symmetrical arrangement of small spots centered around the intensely exposed patch produced by the X-ray beam. These spots were caused by the refraction of the X-rays off of individual atoms inside the crystal. A method had been discovered to observe directly the atomic arrangements of crystals. For this important discovery, Von Laue was award the Nobel Prize in physics.

What X-rays were composed of was speculated on. William Bragg [xxxx-xxxx] believed that X-rays had the properties of physical particles rather than of electromagnetic waves. But he was challenged to interpret the spots caused by crystal diffraction in terms of own theory. His son and student, W. Lawrence Bragg [xxxx-xxxx] , suggested a solution by suggesting that X-rays were electromagnetic radiation of very short wavelength. By placing the photographic plate further back from the crystal being X-rayed, he showed that the spots became elliptical. This showed that the electromagnetic waves were not only diffracted in certain directions, as von Laue theorized, but also reflected like a mirror by some of the layers of atoms in the crystal. Working on the concept that some crystals were composed of atoms in a cubic close-packing arrangement of spherical atoms, he further showed that some of these 'atomic mirrors' reflect X-rays more efficiently than others. With this model he was able to measure the intensity of the reflected beams using an X-ray spectrometer.

In 1913, William Bragg determined that all the metals used in constructing X-ray tubes as sources of radiation give rise to a characteristic X-ray of definite wavelength. He also found that by measuring the angles through which the X-rays are placed on the photographic plate by the various faces of a crystal it is possible to model the arrangement of the atoms in planes parallel to these faces. This method has been successfully used in both X-ray crystallography and in physics and is now known as X-ray analysis. At about the same time, father and son made a systematic study of the atomic structure of various crystals, including rock salt, diamond, fluorine, cuprite, iron pyrites, sodium nitrate, and calcite. From these studies numerous important observations were made concerning the energy quanta according to Planck's law and showing that the shortest wavelength of the various elements are approximately proportional to the inverse square of their atomic weights. For their work they won jointly the Nobel Prize in physics, the son, W.L. Bragg so far being the youngest recipient (age 23 ???).

During and after the First World War other important contributions to X-ray analysis were made. A considerable quantity of data about the atomic structure of substances was compiled, including much on crystallography. The usefulness of this tool has proven its value over the intervening years, having been, for example, instrumental in showing the actual structure of DNA, from which Crick and Watson worked out the double-helix bonding.

## 8.4 Etch Figures[932]

Etch figures are minute pits that form on the surfaces of crystals when treated with solvents. When all other methods had failed a crystallographer it was possible to use etched

[932] Other historical information may be found in: Goldschmidt, V. and F.E. Wright, "Ueber Aetzfiguren, Lichtfiguren und Lösungskörper," *Neues Jahrbuch für Mineralogie, Beilage-Band*, **17** (1903), p. 355-390. • P. Honess, *The nature, origin and interpretation of the etch figures of crystals*. New York, John Wiley and Sons, 1927.

figures to determine the symmetry of crystals and as a means to explore the molecular structure of the crystals.

The first scientific application of the etch method appears to have been published by the mineralogist G. William Thomson [1761-1806] in a generally overlooked paper dated 6 February 1804 that describes the etching of the Krasnojarsk nickel-iron meteorite.[933] Thomson in order to preserve a section of the meteorite treated it with dilute nitric acid to prevent it from rusting. The paper describes the resulting etch figures and shows illustrations thus anticipating the somewhat later work of Widmannstätten who is usually credited with discovering this procedure.

Working in 1808, Aloys Beck Edler von Widmannstätten[934] observed that highly characteristic markings formed on the polished surfaces of meteorites by the corrosive action of acids. He further deduced that the patterns are definitely related to the crystalline structure of the meteoric iron. By using meteorite slices so etched and the application of printer's ink, he was able to reproduce images of the so-called "Widmannstätten structure." Although he never published any of his findings, they were communicated his colleages and in particular Carl Schreibers in 1820 published examples of the distinctive pattern naming it after Widmannstätten.

In 1816, William Hyde Wollaston [1766-1828] published the results of his experiments on a meteoric mass of iron acquired from Brazil.[935] He utilized an acid wash and described the characteristic etch figures.

To John Frederic Daniell [1790-1845] credit is given to the first application of the etch method to crystal faces.[936]

In 1818, Summering published on the meteorite structure[937] and in 1820 Karl Franz Anton von Schreibers[938] published his massive *Beiträge zur Geschichte und Kenntniss meteorischer Stein- und Metallmassen* in which a number of meteorites showing the etch pattern were printed directly to the plates. Hence, the attention of the early investigators were more focused to meteorites than to crystals, and not until years later did the etch method receive serious consideration as an actual means of crystal classification.

In 1824 Frederich Mohs in his *Grundriss der Mineralogie* mentioned that when a crystal of rock salt was kept in a damp environment quadrilateral etch pits would develop on the cube faces. He made similar observations for saltpeter and alum. In 1837, David Brewster [1781-1868] called attention to the natural etchings on the faces of a Brazilian topaz crystal. These so-called "licht-figuren" whould cause other investigators to examine etchings on crystals..

The Austrian mineralogist Franz Leydolt [1810-1859] researched etch figures in his first papers.[939] He described the pits observed on quartz crystals noticing that they were all of similar shape regardless of their size. Utilizing optics to examine various aspects of

[933] G. William Thomson, "Essai sur le Fer Malléable trouvé en Sibérie par le Prof. Pallas," *Bibliothèque Britannique*, **27** (Oct.-Nov. 1804), pp. 135-154, 209-229.; Max Hey, "History of the 'Widmanstätten' structure," *Nature*, **143** (6 May 1939), p. 764.; C.S. Smith, "Note on the history of the Widmanstätten structure," *Geochimica et Cosmochimica Acta*, **26** (1962), 971-2.; John G. Burke, *Cosmic debris*. Berkeley, Univ. of California Press, pp. 124-125, 340.

[934] **Aloys Beck Edler von Widmannstätten** (Born: Graz, Austria, 1753; Died: Vienna, Austria, 10 June 1849) Widmannstätten sold his family's printing business located in Graz in 1807 and moved to Vienna. There he became the director of the royal collections of technological artifacts. In his later years he was pensioned. [DSB, Poggendorff].

[935] William Hyde Wollaston, "Observations and experiments on a mass of native iron found in Brazil," *Philsophical Transactions*, **265** (1816), pp. 281-285.

[936] J.F. Daniell, "On some phenomena attending the process of solution, and their application to the laws of crystallization," *Quarterly Journal of Science (London)*, **1** (1816), pp. 24-49.

[937] ??. Summering, "Über die Zeichnungen welche sich bei Auflosung des Meteoreisens bilden," *Schweigger's Journal*, 1818.

[938] **Karl Franz Anton von Schreibers** (Born: Presburg, Austria, 15 August 1775; Died: Vienna, Austria, 21 May 1852) Schreibers was a physician who for a time had a practice in Vienna. In 1806 he became an assistant in natural history at the University and after the death of A. Stütz, Schreibers became the director of the Royal Natural History Cabinet. He was pensioned in 1851. [Poggendorff]

[939] Leydolt, F., "Über eine neue Methode, die Structur and Zusammensetzung der Krystalls zu untersuchen mit besonderer Berucksichtigung der Varietaten des rhomboedrischen Quarzes," *Berichte Akademie Wien*, **15** (1855), p. 58.; *ibid.*, "Ueber Aetzungen," *Berichte Akademie Wien*, **15** (1855), p. 58 and **19** (1856), p. 10.

the pits Leydolt theorized that they reflected the internal molecular structure of the crystal structure. However, Leydolt prematurely arrived at the conclusion that the shape of the etching was directly connected with that of the crystal molecule. Later investigations by Franz von Kobell[940] and the publication in 1865 of Karl Haushofer's important work, *Ueber den Asterismus and die Brewster'schen Lichtfiguren am Calcit* proved that no such relation exists.

Following Leydolt's first paper he published a second in 1856, entitled, "Ueber die Structur and Zusammensetzung der Krystalle des prismatischen Kalkhaloides," and from this time on, there continued an ever-increasing interest in the etching of crystals, as evidenced by the number and character of the publications brought to light, principally through the efforts of German scientists, during the last four decades of the nineteenth century. During this period many notable contributions were made to the theory and application of the etch method, chief among which are the works of Pape,[941] Reusch,[942] Bauer,[943] Baumhauer,[944] Hirschwald,[945] Exner,[946] Rinne, Klocke,[947] Tschermak,[948] Becke,[949] Hamberg,[950] Ebner,[951] Molengraaff,[952] Penfield,[953] Wulff,[954] Traube,[955] Walker,[956] Daly,[957] Viola,[958] and Beckenkamp.[959]

The general content of these papers comprises a theoretical study of the etch figure in connection with extensive experimental work, involving the etching of many of the common minerals. Such topics as asterism, the importance of the etch figure in isomorphism, the rational or irrational character of the axial intercepts of etch faces, differential solution as exhibited by natural crystals and ground spheres, anomalous etchings, the relation of the etch figure to the crystalline molecule, the conditions controlling the development of the etch figure, and its relation to the symmetry content of crystals are discussed by Baumhauer in a classical work, *Die Resultate der Aetz-Methode in der Krystallographischen Forschung*, published in Leipzig in 1894. This represents Baumhauer's very thorough and untiring study of the etch method covering a period of over twenty years, during which there appeared over thirty separate

[940] Kobell, F.v., "Ueber Asterismus und die Brewsterschen Lichtfiguren," *München, Sitzungsberichte*, **1** (1863), pp. 51-65.

[941] Pape, C., "Ueber das Verwitterungs-Ellipsoid wasserhaltiger Krystalle," *Poggendorff's Annalen*, **124** (1864), p. 329 and **125** (1865), p. 513.

[942] Reusch, F.E., "Ueber die Körnerprobe am Steinsalz und Kalkspath," *Poggendorff Annalen*, **132** (1867), p. 441.; *ibid.*, "Am zwei-axigen Glimmer," *Poggendorff Annalen*, **136** (1868), p. 632.; *ibid.*, "Am krystallirten Gyps," *Poggendorff Annalen*, **136** (1868), p. 135.

[943] Bauer, M., "Untersuchung über den Glimmer und verwandte Minerale," *Poggendorff Annalen*, **138** (1869), p. 337.

[944] Baumhauer, H., "Ueber Aetzfiguren und die Erscheinungen des Asterismus an Krystallen," *Poggendorff's Annalen*, **138**, 163; **139**, 349; **140**, 271; **145**, 459; **153**, 621; *Berichte Akademie München*, 1875, 169.

[945] Hirschwald, J., "Aetzfiguren an Quarz-Krystallen," *Poggendorff Annalen*, **137** (1869), 548.

[946] Exner, F., "An Lösungsfiguren in Krystallen," *Berichte Akademie Wien*, **69** (1874), 6.

[947] Klocke, F., "Alum," *Zeitschrift der Krystallographie*, **2** (1878), p. 126.

[948] Tschermak, G., "Calcit, dolomit, etc.," *Min. Petr. Mitth.*, **4** (1881), p. 99.

[949] Becke, F., "Sphalerite," *Min. Petr. Mitth.*, **5** (1882), p. 457.; *ibid.*, "Galena," *Min. Petr. Mitth.*, **6** (1883), p. 237.

[950] Hamberg, H.E., "Calcit," *Geol. För. Förh.*, **17** (1885), p. 53.

[951] Ebner, V. v., "Die Lösungsflächen des Kalkspathes und des Aragonites," *Sitzungsber. Akad. Wissensch. Wien, Math.-Nat. Kl.*, **89** (1884), p. 368-458 and **90** (1885), p. 760-835.

[952] Molengraaff, G.A.F., "Quartz," *Zeitschrift der Krystallographie*, **14** (1888), p. 173 and **15** (1889), p. 137.

[953] Penfield, S.L., "Quartz," *Transactions of the Connecticut Academy of Science*, **8** (1889), p. 158.

[954] Wulff, L., "The experiments on solubility and etching," *Zeitschrift der Krystallographie*, **22** (1894), p. 473.

[955] Traube, M., "Cuprit, wulfenit, beryl, etc.," *Neues Jahrbuch für Mineralogie und Geologie, Beiligen-Band*, **10** (1896), 454.

[956] Walker, T.A., "On several triclinic minerals," *American Journal of Science*, **5** (1898), p. 176.

[957] Daly, R.A., "A Comparative Study of Etch Figures of the Amphiboles," *Proc. Am. Acad. Sci.*, **34** (1898-99), p. 373.

[958] Viola, C.M., "Homogenitat and Aetzung," *Zeitschrift der Krystallographie*, **31** (1899), pp. 97.

[959] Beckenkamp, J., "Zur Symmetrie der Krystalle," *Zeitschrift der Krystallographie*, **32** (1900), pp. 9-48.

publications by the author bearing on this line of investigation. This work is the culminating point of Baumhauer's investigations, and is the only complete book on etch figures published in the 19th century.

In 1903, Victor Goldschmidt and F.E. Wright reviewed the current state of etch figures and provided exhaustive references to the literature.[960]

### 8.5 Liquid Crystals[961]

Liquid crystals were discovered and studied in the 19th century and were studied primarily by Lehmann, Schenk and Vorlander. By 1908 a theoretical framework for liquid crystals was established and other theoretical studies by E. Bose, Max Born, F. Rhimpf, O. Lehmann, and G. Friedel were made. It was not until after World War II that practical applications for this class of substances were created. Today, every laptop computer, not to mention virtually every digital display utilizes liquid crystals as a display.

## 9.0 Systematic Mineralogy[962]

A good system of classification is not simply a catalogue of facts. Instead it is a tool of applied research, being at its core the very basis of theoretical generalizations. Such a system may arrange its subject upon any number of characteristics such as color, shape, size, chemistry, locality, mode of occurrence, or some combination of these or other criteria. In large part it will reflect current theories and is as a result as imperfect and primitive as those theories upon which it is founded. The evolution of mineralogical classification systems, therefore, closely parallels discoveries in crystallography, physics, and chemistry.

The purpose of mineral classifcation is to orgranize an unorganized mass of descriptive information and to define the supposed relationships between individual mineral species based upon that information. A system that can accomplish this purpose is not simply a listing of facts. It becomes a method in which the facts are set in relation to one another. One use of such a scheme is that properties not immediately detected in on mineral might be inferred because of common features with other minerals in the group. The simple alphabetical listings common in the early history of mineralogy could not set minerals in relation to one another without elaborate cross-references. Thus such an arrangement is less useful than other possible schemes. Another inadequate method is when the minerals are grouped together on the basis of their use. For example, minerals that are used for adornment may be classified as gemstones, but no other general

[960] Goldschmidt, V. and F.E. Wright, "Ueber Aetzfiguren, Lichtfiguren und Lösungskörper," *Neues Jahrbuch für Mineralogie, Beilage-Band*, **17** (1903), pp. 355-390.

[961] Other historical information may be found in: H. Kelker., "History of liquid crystals," *Molecular Crystals*, **21** (1973), p. 1-48. • *ibid.*, "Survey of the early history of liquid crystals," *Molecular Crystals*, **165** (1988), p. 1-43. [Contains information on the early history of liquid crystals especially Otto Lehmann.] • Tim Sluckin, David A. Dunmur, and Horst Stegemeyer, ed., *Crystals That Flow: Classic Papers from the History of Liquid Crystals*. New York, 2004. 738 p. [The introduction contains a valuable history of the discovery of the crystals.; ISBN 0415257891.]

[962] Other historical information may be found in: E.H.M. Beekman., *Geschiedenis der Systematische Mineralogie*. s'Gravenhage, 1906. • John G. Burke., "Mineral classification in the early nineteenth century" (pp. 62-77), in: J.C. Schneer, ed., *Toward a history of geology*. Cambridge, Mass., and London, MIT Press, 1969. • Francisco J. Fabregat., "La sistemática mineral - Bosquejo histórico," *Geologiá y Metalurgía*, **3** (1966), no. 18, p. 9-24, illus. • Franz von Kobell., *Geschichte der Mineralogie. Von 1650-1860*. München, 1864. • J. Lima-de-Faria., "Past, present, and future of the classification of minerals" (pp. 17-28), in: B. Fritscher and F. Henderson, eds., *Toward a history of mineralogy, petrology and geochemistry. Proceedings of the international symposium on the history of mineralogy, petrology, and geochemistry, Munich, March 8-9, 1996*. Münich, Institut für Geschichte der Naturwissenschaften, 1998. • N. Morello., "Mineralogical classifications in sixteenth century Italy" (pp. 53-64), in: B. Fritscher and F. Henderson, eds., *Toward a history of mineralogy, petrology and geochemistry. Proceedings of the international symposium on the history of mineralogy, petrology, and geochemistry, Munich, March 8-9, 1996*. Münich, Institut für Geschichte der Naturwissenschaften, 1998. • David R. Oldroyd., *From Parcelsus to Haüy: the developement of mineralogy in its relation to chemistry. Ph.D. Dissertation*. University of New South Wales (Australia), 1975. • C.S. St. Clair., *The classification of minerals: some representative mineral systems from Agricola to Werner. Ph.D. Diss., The University of Oklahoma*. Ann Arbor, Michigan, University Microfilms, Inc., 1966. • Johan G. Wallerius., *D.D. brevis introductio in historiam litterariam mineralogicam atque methodum systemata mineralogica rite condenda, una cum supplementis*. Holmiæ, Upsallæ & Aboæ, M. Swederi, 1779.

assumption can be made concerning the species of this group other than they are considered gems. Therefore classifying some minerals as gemstones does not clarify the relationships between the individuals, and no theoretical insights can be gained from such a grouping.

This section presents an analysis of attempts to systematize the knowledge of minerals from the earliest times. These early efforts seem strange and they have been obscured by the accomplishments of modern mineralogists, but their work is the foundation for these later systematists. Today the hundreds of mineral classifications proposed by these early mineralogists are now little more than historical curiosities, yet they tell an interesting aspect of the development of mineralogical science.

## 9.1 Concept of Species[963]

The first and perhaps most important question that should be asked when dealing with mineral systematics is "What is a mineral?" Or more importantly, what exactly are the objects that are being classified. Not surprisingly the answer to this question, which reflects beliefs in place at the time of the classification, has changed over the years. Also implicit in the answer is the idea of what constitutes an individual within the science, and that concept is echoed back into the system of classification. It seems appropriate to first investigate what is meant by "mineral" before progressing to the history of the various systems of mineral classification.

### 9.1.1 Derivation of 'Mineral'[964]

The term *mineral* has changed considerably from its ancient origins. The old Greeks did not have the word in their vocabulary but they did have the word λιθικα (*lithica*) which means "of stones." They also had the term ὁρυκτός (*orykto*) that means "to dig," and which they used to designate inanimate objects dug from the earth. It generally referred to metals, minerals, stones, and fossils.[965] This became the root for the obsolete English words *oryctognosy* and *oryctology*.[966] Later Latin writers employed other words that are frequently encountered in the early mineralogical literature. *Metallum* was used to designate metallic ores while *lapis* generally identified stones and rocks, but especially the silicates. *Fossilium* was

[963] Other historical information may be found in: J.W. Gregory., "The definition of mineral," *Transactions of the American Institute of Mining Engineers*, **40** (1909), p. ??-??. • R. Hooykaas., "The species concept in eighteenth-century mineralogy," *Archives International d'Histoire des Sciences*, **5** (1952), p. 45-55. • *ibid.*, "The concept of 'individual' and 'species' in chemistry," *Centaurus*, **5** (1956), p. 307-322. • H.H. Kubbinga., *Le développement historique du concept de 'molécule' dans les sciences de la nature jusqu' à la fin du XVIIIe siècle*. Paris, 1983. 224 p. • Seymour H. Mauskopf., "II. The molecular 'individual' and III. Mineral species and quantified chemistry" (pp. 14-20 and pp. 21-32, respectively) in: "Crystals and compounds: Molecular structure and composition in nineteenth-century French science," *Transactions of the American Philosophical Society*, **66** (1976), p. 1-82. • Ernst Mayr ., "What is a Species, and What is Not?," *Philosophy of Science*, **63** (1996), p. 262-277. • M.J. Orcel., "Haüy et la notion d'espèces en minéralogie," *Bulletin Societie Mineralogie*, **67** (1944), p. 265-306. • *ibid.*, "Espèces minérales dont Haüy a donné la véritable définition," *Bulletin Societie Mineralogie*, **67** (1944), p. 307-335. • *ibid.*, "Essai sur le concept d'espèce et les classifications en mineralogie et petrographie. Aperçu historique et philosophique," *Revue Roumaine de Geologie, Geophysique et Geographie*, **10** (1966), p. 3-39. • A.S. Povarennykh., "On the development of the definition of the concept mineral" (pp. 35-57), in: M.H. Battey and S.I. Tomkeieff, eds., *Aspects of theoretical mineralogy in the U.S.S.R. A collection of papers*. Translated from the Russian. New York, The Macmillan Company, 1964. [Treats the historical development of the concept of a mineral species.] • C.S. St. Clair., *The classification of minerals: some representative mineral systems from Agricola to Werner. Ph.D. Diss., The University of Oklahoma*. Ann Arbor, Michigan, University Microfilms, Inc., 1966. [4], vii, [1], 298 p. • H.-W. Schütt., "Beudant, Berzelius und die mineralogische Spezies," *Gesnerus*, **41** (1984), p. 257-68. • A.N. Winchell., "What is a mineral?," *American Mineralogist*, **34** (1949), nos. 3-4, p. ??-??.

[964] Other historical information may be found in: *Oxford English Dictionary*, "Mineral," **??**, p. ??-??.

[965] Henry G. Liddell and Robert Scott., *A Greek-English Lexicon*. 9th edition. Oxford, 1953, p. 1257.

[966] In 1774, Abraham Gottlob Werner in his famous *Von den äusserlichen Kennzeichen der Fossilien* defined "Oryctognosy" as that portion of mineralogy that taught the recognition of minerals through the testing of well established physical characters. Oryctognosy is thus the science of the determination of minerals. Earlier, *oryctogia* was used to describe the study of minerals in general. For example, Élie Bertrand in his *Dictionnaire Universel des Fossils* (1763) used a similar term *oryctology* in a way that it meant by today's understanding the whole of earth science including geology, mineralogy, crystallography, paleontology, and vulcanology. Although prevalent in the 17th and 18th centuries words derived from *orycto* lost favor in the mid-19th century and are no longer employed in mineral science.

employed to describe natural bodies dug up from the earth and traces it origin back to classical Roman antiquity. It became the root for a number of terms including towards the end of the 18th century, *fossilogy*, used singularly as a synonym for mineralogy[967] and the present *fossil*, used to describe the petrified remains of once organic objects.

The word *mineral* may have a Celtic root (*mina*) and apparently entered the vocabulary of Middle English about 1390 from the Medieval Latin *minerale*, "something mined" and from the neuter form of *mineralis*, "pertaining to mines," leading to minerals being defined in the Middle Ages as a "substance obtained from mining." By the middle of the 17th century, students of mineralogy began to favor its use above the earlier terminology, developing new words from the root. The term *mineralogist* seems to have appeared first in English in Sir Thomas Browne's *Pseudodoxia Epidemical or Enquiries Into Very Many Received Tenets, and Commonly Presumed Truths*, first published in London in 1646. Referring to the popular notion that rock crystal was permanently congealed water, Browne noted that many of the "exactest mineralogists" refuted this.[968] As for the word *mineralogy*, or the science of minerals, the first use of this term appears to have been made in 1636 in the title to Bernardo Cesi's *Mineralogia, sive Naturalis Philosophiæ Thesauri*, but it did not catch on immediately. Later, Robert Boyle in his 1690 essay *A Previous Hydrostatical Way of Estimating Ores* wrote:

"...our impractised way of estimating ores, may not be useless; and for that reason will not perhaps be unwelcome to some that love mineralogy, much better than they understand it; especially coming forth at a time when many industrious persons of this nation are excited to look after profitable minerals..." [969]

Boyle called practitioners of mineral science or people "skilled in the Knowledge of Minerals" as "mineralists," a name that came to be used much less frequently than Browne's derivation "mineralogist." Clearly after the term *mineral* was introduced into the language, it and its derivatives were quickly adopted to distinguish the study of minerals from other persuits of nature.

### 9.1.2 Minerals and Species[970]

Besides the evolution of the terminology used in mineral science there are the philosophical ideas that stand behind what the terminology describes. Perhaps the first question to ask in this instance is, what is a mineral? During the long history of mineralogy the understanding of this question has changed considerably. For a very long time it was a common view that minerals reproduced like plants inside the earth. Yet, the old mineralogists considered anything dug from the earth and *not* obviously living as a mineral substance. This allowed them to distinguish mineral materials from various subterranean plants and animals.

Starting from the first recognition by humans about stone and ending with the separation of the science of mineralogy at the end of the 18th century, the concept of what a mineral was embraced a very wide group of objects—in fact the whole of inorganic nature. This content was fluid, changing, deepening, and expanding as the study delved deeper into the essence of the objects it was investigating, gradually bringing to light their complexity. These studies honed the science into an ever sharper and sharper focus, differentiating minerals from other earthly substances. But this took a very long time. The ancient Greeks, particularly Aristotle and Theophrastus, included all the substances of an inorganic nature within their realm of the mineral kingdom. Later mineralogists of the 16th and 17th century, such as Agricola, Gesner, and Boodt used essentially this same definition to define the objects of their study.

The objective of these early mineralogists was how to categorize their minerals not examine what they are. For example,

[967] G. Edwards., *Elements of Fossilogy*. London, 1776.

[968] T. Browne, *Pseudodoxia Epidemica*. London, 1646, p. 34.

[969] R. Boyle, *The Works of the Honourable Robert Boyle*,Thomas Birch, editor. London, 1772, **5**, p. 489-490.

[970] Other historical information may be found in: H.-W. Schütt., "Beudant, Berzelius und die mineralogische Spezies," *Gesnerus*, **41** (1984), p. 257-268.

Albertus Magnus [1193-1280] divides his universe into stones, metals, fossils, and minerals in his *De Mineralibus* that was written about 1260. Although it is a compilation from earlier writers it also contains the author's own rich observations about minerals. Following ancient thoughts, particularly Aristotle, the 70 minerals and stones described were considered as being formed inside the earth from some elemental form of Earth and Water under the influence of Fire and Ice. Interestingly, Albertus likewise considered all the stones formed in the kidneys and bladders of animals as being made of the same material.[971]

The "Father of Mineralogy" Georgius Agricola [1494-1555] noted in 1546 that although minerals do not have the variety of origins that are found in living matter, they vary greatly in color, transparency, luster, odor, brilliance, taste, and other properties. They are formed from what he called "original matter," as were all other things. He followed the same believes of those writers that came before him and considered all things that came from the earth as being mineral in nature. By character a practical man Agricola utilitarian approach to mineralogy had great influence long after his time.[972]

By the 17th century the study of minerals was still haphazard and arbitrary, however, students of minerals had acquired sufficient knowledge and direction of purpose to begin identifying and distinguishing the substances they studied. At the century's start, minerals were regarded as comprising anything dug up from the earth or found underground, and knowledge of these "dug up" objects was contained in a variety of books that did little more than describe them. But increasingly mineral substances were coming under scrutiny by the scientists, and questions about their nature and origin were repeatedly raised and discussed in an ever increasing number of scientific journals and books. The *Mineralogia, sive Naturalis Philosophiae Thesauri* of Bernardo Cesi [1581-1630] published posthumously in 1636 from notes he left is a compendium of all he ever discovered or read about mineral science. The work is a vast storehouse of all things mineralogical, including new ideas, restatements of earlier authors, observations and superstitious believes. To define his subject Cesi follows and continues to subscribe to the definition that minerals were anything inanimate dug from the earth. But things were changing.

John Harris [1667?-1719] defined "minerals" in his *Lexicon Technicum* (1704) as "hard Bodies dug out of the Earth or Mines, (whence the Name) being part of a Metalline, and in part of a Stony Substance, and sometimes with some Salt and Sulphur intermixed with the other."[973] This definition makes an explicit declaration that minerals contain either a metal, earth, salt, or sulfur component, but does not mention how they form. It was a broad definition and other terms became synonymous to minerals. For example "native fossils" were defined as "sensible Bodies generated, and growing in, and of the Earth; whose constituent Parts are so simple, and homogeneous, that there is no apparent Distinction of Vessels, and Juices; between the Part and the Whole."[974]

Naturally the diversity of the objects of mineralogy found full expression in definitions of the period. Johan Gotschalk Wallerius [1709-1785] described minerals in his famous textbook *Mineralogia, eller Mineralriket* of 1747 as:

"Minerals are the objects of mineralogy, which is the knowledge of mixed, compounded and inorganic substances that unceasingly wax and grow although in

[971] Albertus Magnus., *Book of Minerals* Translated by Dorothy Wyckoff. Oxford, Clarendon Press, 1967, p. 11-13.

[972] G. Agricola., *De Natura Fossilium (Textbook of Mineralogy)*. Translated from the First Latin Edition of 1546 by Mark Chance Bandy and Jean A. Bandy. New York, The Geological Society of America, 1955, p. 5, 11-14.

[973] J. Harris., "Minerals" (pp. ??-??) in J. Harris, *Lexicon Technicum, or an Universal English Dictionary of Artis and Sciences, Explaining Not Only the Terms of Art, but the Arts Themselves*. London, 1704.

[974] E. Chambers., "Fossil Kingdom" (pp. ??-??) in: *Cycolopedia, or an Universal Dictionary of Arts and Sciences, containing the Definitions of the Terms and Accounts of the Things Signify'd Thereby, in the Several Arts, Both Liberal and Mechanical, and the Several Sciences, Human and Divine; the Figures, Kinds, Properties, Productions, Preparations, and Uses, of Things Natural and Artificial*. London, 1728.

their inner parts or veins they have no sap whatever." [975]

Another Swedish mineralogist, who examined minerals from the standpoint of their chemistry, Axel Frederick Cronstedt [1722-1765] in many respects was ahead of his time when he recognized that fossils and petrifications were not true minerals and should be excluded from studies of mineralogy.[976] This contradicted the general opinion among mineralogist of the time who accepted as minerals many petrifications and rocks. Additionally, Cronstedt introduced the term *zeolite* in 1756 for certain silicate minerals in allusion to their behavior on heating in a borax bead (from the Greek, ζεο (*zeo*), which means "to boil" and λιθος (*lithos*), which means "stone"), a category that extends to the present day.

In mid-18th century France, the study of minerals was defined as "the part of natural history that is occupied with knowledge of the substances of the mineral kingdom; that is to say, of the earths, stones, salts, inflammable substances, petrifications, in a work of the bodies inanimate and note provided with sensible organs that are found in the bosom of the earth and at its surface." [977] Interesting in this definition is that the material is explicitly stated to be "inanimate," and implicitly not living. Considering that it was still common to believe in this age that minerals and metals grew with in the earth in processes similar to animals and plants this definition was somewhat extraordinary. It was not until the understanding of chemistry a few decades later that the actual processes that formed minerals inside the earth were glimpsed, putting an end in scientific circles to the idea that minerals "grew."

The influential Irish mineralogist and chemist Richard Kirwan [1733-1812] definition of a mineral concentrates on their chemical composition. In 1784 he wrote:

"Minerals in their strictest signification denote only such substances as are found in mines, such as Metals, Semimetals, Sulphur and Salts; but in a more extensive sense, they denote all fossils that do not belong either to the vegetable or animal kingdoms, and consequently Stones. and Earths, all of which are comprehended under the Denomination of the Mineral Kingdom." [978]

Thus at the end of the 18th century conditions were in place to differentiate a science of minerals. But that separation could only happen after progress, in the closely allied sciences, physics, chemistry, and biology had reached a particular level. The first science to break away from mineralogy was the so-called geognosy that ultimately became the study of geology, which was officially separated by Werner in 1785. The foundations of biological evolution created by the research of Smith, Cuvier, Oken, Lamarck and others as well as the successful results from the comparative method in anatomy and physiology made it possible to detach paleontology as a separate science at the beginning of the 19th century. Almost at the same time establishment of the basic laws of polyhedral crystalline matter by Romé de l'Isle, Haüy, Weiss, and others began the separation of crystallography from mineralogy. In this way a critical stage in mineralogical history was set by limiting the type and number of objects the science investigated.

Jöns Jakob Berzelius [1779-1848] in his *An Attempt to Establish a Pure Scientific System of Mineralogy* (1814) did not feel it necessary to give an explicit definition of minerals, believing that the term was well enough understood as not to need one.

Mineralogy, in the usual acceptation of the word, is tbe science which treats of the combination between the anorganic elements which are found upon or beneath the surface of the earth, together with tbe various forma, and the different foreign admixtures, under which these bodies make their appearance.

Parker Cleaveland [1780-1858] in 1816 defined minerals as "those bodies, which are destitute of organization, and which naturally exist within the earth, or at its

[975] J.G. Wallerius., *Mineralogia, eller Mineralriket*. Stockholm, 1747, p. 3.

[976] A.F. Cronstedt., *Försök till Mineralogie, eller Mineral-Rikets Upställning*. Stockholm, 1758.

[977] *Encyclopédie, ou Dictionnaire Raisonné des Sciences, des Arts et des Métiers, par uns Société de gens de Lettres*. Paris, 1765, **10**, p. 541.

[978] R. Kirwan., *Elements of Mineralogy*. London, 1784, p. 1.

surface."[979] He goes on to explain that fossils are formerly organic creatures and their study belongs more appropiately to geology. Frederich Mohs [1773-1839] simply says that "The inorganic productions of Nature are altogether comprehended under the name of Minerals."[980]

Chemistry was the only means that was used by Thomas Thomson [1773-1852] in defining his minerals in 1836. He goes on to say they must be homogeneous mixtures otherwise they are not minerals.

> The term mineral is applied to all the solid materials of the globe, when these materials are homogeneous, or composed of one substance aggregated together in masses, as is the case with sulphur, iron, antimony, diamond, &c., or when they are composed of two or more constituents united together in chemical proportions. ... When a mineral is not composed of constituents united together in chemical proportions, but which vary in different specimens, such minerals are considered merely as mechanical mixtures, and belong not to mineralogy, but geology.[981]

From then onwards among the essential characteristics of a mineral was that it be a homogenous substance. Hence the concept of the mineral shrank while on the other hand its content expanded. This framework also laid a foundation that would gradually include liquids and even gaseous natural inorganic substances among minerals. As a natural result the definition of the science of mineralogy itself had to be changed. This was true in 1837, when James Dwight Dana [1813-1895] issued the first edition of his important and famous *System of Mineralogy* that described the objects of his study:

> The Mineral kingdom, on the contrary, contains those natural objects that are not possessed of life: objects which increase by accretion merely, or an external addition of particles, unaltered by any powers of assimilation in the object; which are equally perfect in the embryo state, or at the earliest commencement of their formation, and in the enlarged individual; whose individuality is Hot destroyed by a separation of parts; whose formation is originally the result of chemical attraction, and, consequently, they are not, from their nature, necessarily liable to decomposition.[982]

One of the best conceptual definitions of "mineral" that shows the level of mineralogical knowledge in the middle of the 19th century is from Nicolai Ivanovich von Koksharov [1818-1893]. He writes:

> "A mineral is any homogeneous, solid or liquid substance which is an immediate product of nature originating without the participation of organic processes, independently of the will of man."[983]

This definition excluded objects that were transformed from organic substances such as coal, lignite, amber and some fossil pitches as reckoned as minerals.

Until the mid-19th century, the gauge of how homogenous a particular mineral was through macroscopic examination because their was only negligible application of the microscope in mineralogical research. Consequently the distinction of minerals from rocks was very imperfect. It was not until soon after the introduction of the polarizing microscope in 1858 that rocks could be readily distinguished from minerals and the science of petrology splinttered off from mineralogy.

Comparing common elements of the concept "mineral" there is a considerably difference in their content. In the 18th century definition there are only principal characteristics: (1) solid, (2) inorganic in nature, and (3) formation by accretion of particles from the surrounding medium. In the 19th century the definition was extended by adding other characters: (1) physically homogenous, (2) the liquid state, (3) origin by inorganic natural processes, and (4) distinction from synthetic (artificial) products. These characteristics not only exclude rocks and fossils from among minerals but also all gases, calculi (urinary and hepatic), corals, bones and all inorganic laboratory products. However, physical homogeneity still allows

[979] P. Cleaveland., *An Elementary Treatise on Mineralogy and Geology*. Boston, 1816, p. 1.

[980] F. Mohs., *Treatise on Mineralogy*. Translated by W. Haidinger. Edinburgh, 1825, **1**, p. 1-6.

[981] T. Thomson., *Outlines of Mineralogy, Geology, and Mineral Analysis*. London, 1836, **1**, p. 3.

[982] J. Dana., *System of Mineralogy*. New Haven, 1837, p. 1-2.

[983] N.I. von Koksharov., . St. Petersburg, 1863.

various cryptocrystalline substances, earths and glasses to be retained as minerals.[984]

With the growth of mineralogical knowledge the number of representatives of these groups increased steadily, but at unequal rates. A part of them namely cryptocrystalline substances, was gradually excluded from the objects of mineralogy because it was demonstrated that they were polymineralic in composition and heterogenous, i.e., a rock. Finally by the turn of the century, the definition of a mineral includes an explicit declaration that it has a crystalline structure:

"a naturally occurring body produced by inorganic processes, which possesses a definite chemical composition and a definite molecular structure. This definite molecular structure is manifested in the crystalline form, the cleavage, and the behavior of the mineral towards transmitted light and heat. A mineral is homogeneous in composition and structure, in contradistinction to a rock which is generally a mixture of different mineral species, and always an aggregate of mineral individuals, and hence is heterogeneous in composition, or structure, or both." [985]

With in mineralogical science then the original concept that it should be the study of everything that originated from the earth gave way to the idea that minerals were separate from fossils and rocks, as being a homogenous substance that is crystalline in structure. But it required centuries of experimentation and philosophical pondering to come to this conclusion.

## Mineral Species

The fundamental unit of mineralogy, particularly with respect to aspects of its classification, is the *mineral species*. The concept of a mineral species dates from the 18th century when classifications and nomenclatures were devised for the three natural kingdoms: plants, animals, and minerals. The basic and fundemental element to these studies were the species, and borrowing from the biological terminology it is common to refer to the individual members of mineralogical science as a mineral species. In this connection it is interesting to note that throughout the 18th and into the 19th century a binomial nomenclature like that now used for plants and animals was applied to minerals (see §10.0).

The French botanist and mineralogist, Louis-Jean-Marie Daubenton [1716-1800] drew a sharp distinction between organic matter and minerals. He felt that minerals were different from plants because they lacked a common external form and did not possess life. He recogonized that these differences generated serious problems for the classifier, because it was impossible through external form alone to specify the mineral analogue to the "individual" plant or animal. Additionally Daubenton speculated that since there were no mineral species and no reproduction in the biological sense occurred, this meant a constant set of characteristics could not be maintained over time, as living things could, which made classification impossible.[986]

But this was symptomatic of the larger question as to if mineral species could be efficiently classified that occurred at the end of the 18th century. At that time some naturalists believed that since they did not possess a uniform external structure like plants and animals, minerals could not be classified accurately. Daubenton extended this view suggesting that no distinct mineral species existed. This view had a considerable influence on mineralogy. If minerals really could not be accurately defined as species, what was the point of mineralogy then one of the major objectives of mineralogy could not be achieved.

Throughout all of his crystallographic work Romé de l'Isle implicitly accepted that distinct mineral species existed. But it was in the *Des Caractères Extérieurs des Minéraux* (1781) that he first refutes Daubenton's contention. He insisted that the defining

[984] A.S. Povarennykh., "On the development of the definition of the concept mineral" (pp. 35-57), in: M.H. Battey and S.I. Tomkeieff, eds., *Aspects of theoretical mineralogy in the U.S.S.R. A collection of papers.* Translated from the Russian. New York, The Macmillan Company, 1964. [Treats the historical development of the concept of a mineral species.]

[985] Henry Erni and Amos Peaslee Brown., *Mineralogy Simplified: Easy Methods of Identifying Minerals, Including Ores.* 4th edition. Philadelphia, 1908, p. 1.

[986] R. Hooykaas., "The species concept in eighteenth-century mineralogy," *Archives International d'Histoire des Sciences*, **5** (1952), p. 45-55.

characteristic of mineral species was a constant chemical composition, and Romé looked to the chemists to supply the supporting evidence in the future. For the time being however, he believed that every mineral species is defined by three properties: hardness, specific weight, and (primitive) crystal form.

Chemistry was also at the heart of Abraham Gottlob Werner concept of a species. He considered that "All minerals composed of the same constituents combined in the same proportion belong to the same species, while minerals composed of different constituents belong to distinct species."[987] Haüy, on the other hand, although recognizing that species were probably composed of the same chemcial constituents, believed first and for most that distinct mineral species had to have the same integrant molecule, or crystalline structure.

But this was a time when quantitative analysis of minerals was still highly inaccurate and the results being reported were so variable that a satisfactory definition of a mineral species through chemistry alone could not be given. In fact some mineral species, notably the silicates, which contain the same element in different proportions, would have led to confusion if their true formulas were known. Consequently neither crystallography or chemistry alone could provide a solid theoretical foundation to define what a mineral was.

Add more about the idea of mineral species in the 19th century.[988]

By the mid-19th century the majority of mineralogists regarded all specimens of a given mineral species as absolutely identical amongst themselves. Practically all of the attention of investigators was directed to the study of the morphology, physical properties and chemical composition of minerals. The mineral classifications of Werner's, Cordier's and Mohs's were based on the morphology and physical properties of minerals as were the purely crystallographic systems of Rose and Frankenheim. These gradually made way to the chemical systems developed by Berzelius, Beudant, and Dana. Only at the end of the nineteenth century under the influence of advances in sciences close to mineralogy (especially physical chemistry) and also of evolutionary ideas in biology and geology, does a dynamic outlook of mineralogy begin to appear. This happened through the experimenters who established parameters for how minerals formed in the crust of the earth.

## 9.2 Classical Sources

A wide range of mineral substances are mentioned and discussed in the literature of classical antiquity, however these were usually incidental to other topics being discussed.[989] One of the earliest known categorization of minerals and one of the most influential was that of the peripatetic school of Aristotle, which employed a tripartite classification method based upon reaction to fire and water. Such a method reflected the Greek belief that all physical matter was composed of a combination of earth, air, fire and water. In his *Meteorologica*, Aristotle mentions about two dozen mineral substances including alum, amber, carbuncle, cinnabar, mill-stone, clay, salt, stalactites as well as the six classical metals—gold, silver, copper, lead, tin and iron.[990] Aristotle explained that mineral substances were created from the interaction of the sun's rays with the earth creating two exhalations, one 'vaporous' and one 'smokey'. According to the characteristics of their origin, he distinguished two groups as follows.[991]

A. *Fossilia*, created within the earth from dry exhalations, are said to be composed of either 'colored powders' or are stones formed from such, and are either liquidifiable or non-fusible. This group contained ochre, sulphur and minium.

B. *Metallica*, originate from the earth's moist exhalations and are either fluid or moldable.

[987] R. Chenevix., "Reflections on some mineralogical systems," *The Philosophical Magazine*, **36** (1810), p. 245.

[988] H.-W. Schütt., "Beudant, Berzelius und die mineralogische Spezies," *Gesnerus*, **41** (1984), p. 257-268.

[989] Lenz, *Mineralogie der alten Griechen und Römer*, 1861. • Moore, *Ancient Mineralogy*, 1834.

[990] Aristotle, *The works of Aristotle translated into English*. Edited by J.A. Smith and W.D. Ross. Oxford, At the Clarendon Press, 1908-1952. [see volume 3.].

[991] W.D. Ross, *Aristotle*. London, 1923, p. 109.

However, Aristotle's writings on minerals were incidental to other topics he wrote about. It was left to his associate and successor Theophrastus to provide a more through explanation of minerals.

In his *Peri Lithon* (Π*epi* Λ*iqwv*)[992] Theophrastus describes about seventy mineral substances with hardly any theoretical speculation and hardly a trace of the superstition that prevaded the later 'lapidaries'. Implicit with in the text is a system of mineralogy that may be inferred from his descriptions.

Theoprastus built upon Aristotle's framework giveing a similar division of ores, stones and earths. The last he divided, however, after the manner of their cleavage and shape like was found in precious stones or marble. This grouping was again split into three sections:

A. *Lapides*.
   1. *Gemmae*, are derived from a pure and homogenous earth and are scarce. This includes emerald, ruby, etc.
   2. *Vulgares*, that are divided according to whether they are fusible or whether they are reducable to lime if sufficiently heated [i.e. marble], or whether they will crack or explode like amber if heated.
   3. *Minus Pretiosi*, like hematite and coral.
   4. *Lapides Metallici*, such as ochre and orpiment.

B. *Terrae*, which Theoprastus states are weak or fusible.

By recording the properties in the descriptions, this system shows a large improvement over Aristoteles attempt. Theoprastus is in fact one of the first attempts prior to the sixteenth century that treat mineralogical objects for themselves rather than for their magical or curative properties.

The most popular work that would be studied in later centuries was Pliny's *Historia Naturalis*. Listed in five books at the end are a large number of minerals. But they are not arranged in any systematic order, so this influential work had little impact on the rise of systematic mineralogy.

The division of minerals according to their manner of origin became the basic scheme, eventhough attempts in various degrees to distinguish the chief groups from each other by means of fixed characteristics developed. A subtle change occurred, however. The foundation of subsequent systems began to be based on the whole external nature of the mineral.

For example the classification of Dioscorides found in *Opera omnia comment ... Lib. V*. He took notice of the place where the minerals were formed and found, in the sea or on the land, and in this way derived the following system:

A. *Marina*.

B. *Terrestria*.
   1. *Lapides metallicos*, in which he counts many earths and sulphours dust.
   2. *Lapides simpliciter ita vocatos*, in which he counts Arabicum (probably soapstone or steatite) and amianthum (probably sapphire).
   3. *Terras*, where Cimoliam, Pnigitem, probably the Marl and clay species are accomadated.

Because there was really no pressing need, scant attention was given to mineral systematics over the next centuries.

## 9.3 Medieval Ideas

### 9.3.1 Avicenna

A milenia after the early Greek and Roman researches, comes the next major advance in systemizing minerals. Arabia produced many learned scholars, among whom Abū ʿAlī al-Ḥusayn ibn ʿabdallāh ibn Sīnā , commonly written Avicenna, was perhaps the greatest. He authored many diverse works in his life time, one of which, a book on medicine, became the standard textbook in the European school for five centuries. Before his medical exploration, however, he studied alchemy and thus came to inquire about minerals in his *Kitâb al-shifâ'* (Book of the remedy).

The system of Avicenna in relation to those from Aristotle and Pliny is comparatively natural. In his *De Mineralibus Tractus*, the following division is given:

1. *Lapides* [Stones], which include the earths.
2. *Metalla* [Fusible substances], which melt in the fire.
3. *Sulphura* [Sulphurs].
4. *Salina* [Salts], which include salt, alum, etc.

[992] Theophrastus' Π*epi* Λ*iqwv*, often called the *De Lapidibus* by its translators has appeared in nine editions and translations.

Avicenna states that this division occurs for the following reason:

> Some of the mineral bodies are weak in substance and feeble in composition and union, while others are strong in substance. Of the latter, some are malleable and some are not malleable. Of those which are feeble in substance, some have the nature of salt and are easily dissolved by moisture, such as alum, vitriol, sal-ammoniac, etc., while others are oily in nature and are not easily dissolved by moisture alone, such as sulphur and arsenic ... All malleable bodies are fusible, though sometimes only indirectly, whereas most non-malleable substances cannot be fused in the orthodox way or even softened except with difficulty.[993]

The system of Avicenna is founded upon a primitive chemical knowledge. Yet this system was largely overlooked in later periods, and in its place arose many whimsical classifications. As a whole, mineralogy was static, making no advance, because all the fables, perpetuated by the Greeks, became an authority to obstruct scientific study. In addition, the middle ages came as a period when emphasis was placed on theological and philosophical studies rather than experimental investigation.

### 9.3.2 Albertus Magnus

The one refuge in the bleak territory of the mediaeval natural sciences in Europe was Albertus Magnus. Of his many books about nature, there are several well executed independent studies. The fables that held fast his contemporaries, did not overly influence him. Instead he endeavored to prove or disprove what he could by investigation; however, he did not always succeed owing to poor judgement. Repeatedly he relates this or that story, although he maintains no faith in it. In essence, Albertus Magnus was a kind of prophet of his time because although rooted in ancient myths and superstition, he nonetheless followed a course which shows a great faith in the exactness of nature. For example, one great advance he made was to take notice of the crystal forms which his predecessors paid so little attention. He noted that the crystallization was a definite attribute of the substances constituent matter, and although he does not fully grasp its worth, he attempts to connect it with his theory of form, which is actually not to distant from the truth.

His classification was less correct. He follows the system of Avicenna, such as he himself states, and gives the following divisions in Beati Albi Magni etc. *Operum tomus sec. De Mineralibus*:

1. *Lapides*, which are non-fusible. They are subdivided alphabetically by the first letter of the mineral's name.
2. *Metalla*, which melt in the fire, for example, mercury, silver, tin, copper, etc.
3. *Media*, such as sal, alum. This group consolidates the third and fourth divisions of Avicenna's system.

After Albertus Magnus there is a void in the history of systematic mineralogy. This period can safely be termed static, because no new system of merit appeared until the sixteenth century. Yet during this time an under current begins to develop that leads to a new period that would be a great advance.

Mining became a more common industry. As early as the sixth century slaves began development in Bohemia, which from the 10th century until the 14th century would prosper. In 920 c.e. the great copper slabs of Frankenberg in Hessen were discovered, and in 935 c.e. the ores of Rammelsberg. The 11th century saw the emergence of mining in Hungary and in the Oberharz of Germany. A century later exploitation of Saxony, Mansfeld, and The Netherlands became widespread. Salt mining began at Wielezska, Poland in the 13th century as did gold recovery from the auriferous copper ores at Fahlun, Sweden. The 14th century witnessed the rising use of amalgamation in Bohemia, the growing iron industry in Silezil and gold refining at Fichtelgeberge. In 1490 mining began in Beneden-Harz, in 1497 in Krain bei Idria, etc. Because of these and similar developments, the deplorable state of mineralogical knowledge became apparent particularly in relation to metallurgical processes. This was one reason for a renewed interest in gathering mineralogical data. Add to this the invention of the printing press in the middle of the fifteenth century, which facilitated the diffusion

[993] Holmyard & Mandeville (1927), p. .

of knowledge, and the result was that the ancient ideas for so long accepted, began to be rejected in favor of experimentation and verification.

## 9.4 The Renaissance

With few exceptions tabulations of minerals through the fifteenth century were usually presented alphabetically with no attempt at subdivision. The sixteenth century, however, saw attempts to group minerals on the basis of external properties. Although the period shows classification in a seemingly confused state, the first criteria for classifying a mineral correctly is to be able to distinguish it from other minerals. Therefore, it is appropriate that the general methods for distinguishing minerals are listed.

1. Locality and Manner of Origin. The location is often employed prior to the principal division, because many during this time believed that quartz from one locality was a completely separate kind then quartz from another (even nearby) location. Not until chemial theory developed would some begin to theorize that a species is a species, regardless of its location. A parallelism developed that the location influenced the manner of origin of the species [which is certainly true of things like kidney stones]. Therefore, many systems utilized location and manner of origin as an important method of distinguishing different kinds.

2. Use. This was employed by many researchers as a distinguishing characteristic. It is rather convenient to classify minerals according to their medical uses or for what purpose the mineral works best. For example, roofing slate was often distinguished from other types of slate, and the Armenian stone, which when mixed with water produced a strong copper that solution was recommended as a stimulant.

3. Size, Color, Taste, Feel, and Transparency, properties which one could easily ponder while at the same time observing them. Common distinctions are: large and small, scarce and common, hard and soft, pretty and ugly, opaque and transparent.

4. Structure. This character incorporates the habit of the specimen. For example, divisions of leafy, thready, dense, granular, complex, brittle, coarse-grained, and fine grained, were used. Often a single species that had many different habits would be classified several different times.

5. Hardness. Employed as a relative characteristic, it hung completely on what the author defined to be "hard" and "soft", because at the time this is the only distinction made. For example, those stones harder than marble were segregated from those not harder.

6. Solubility in Water or Oil, Fusibility and Behavior in Fire. These characteristics, resulting from deliberate experimentation, began to make their appearance. Although the early attempts were rather crude (sometimes amusingly so), these methods eventually stepped to the foreground, displacing the other methods of distinguishing minerals. Consequently, the basis of mineral classification were also changed.

It was upon these broad characteristics that systems of mineralogy were prepared. In fact the beginning of modern mineralogy can be traced to the time period.

### 9.4.1 Stella

Erasmus Stella was the town physician at the mining center of Zwickau in Saxony. In 1517 he authored a short lapidary of 21 unnumbered quarto leaves titled *Interpraetamenti Gemmarum Libettus*.[994] Departing from the alphabetical arrangement of older lapidaries, Stella groups his stone descriptions into four classes according to their color: white, green, read and blue or black. In this manner thirty-three minerals are arranged and given extended descriptions while other stones are mentioned by name alone. The longer descriptions give a more detailed picture than most other previous lapidaries with little or no credence given to magical or supernatural attributes. The most important facet of this work however is that it attempts in some manner to systematically arrange the minerals, which is perhaps the first explicit attempt after the invention of printing.

### 9.4.2 Agricola

[994] Erasmi Stettae *Libonolhani Interpraetamenti Gemmarum Libettus unicus*. Nuremberg, Fredericus Peypus, 1517.

If all the research during the time since man first recognized and attempted to explain minerals were likened to a span of life, then the period starting around 1550 can be termed the start of mineralogy's adolecence. More precisely, it is the era when researchers did not feel compelled to accept ancient believes as uncritically as they had once, and consequently it is during this time that mineralogy started down its path to becoming a rigerous science. The mystical virtues attributed to minerals throughout the previous millenia are still repeated in the literature, but a new style, based on actual observation, is beginning to take hold.

George Bauer, latinized to the more famous Georgius Agricola was the greatest influence in mineralogy and mining during the sixteenth century. Originally a phyisician and linquist, his activities during the years 1527 to 1534 in Joachimsthal, Saxony drew him into a lifelong persuit of mining and mineralogy. These studies inspired his most famous work, *De Re Metallica*, in which a large number of superior woodcuts illustrate medeival mining and metallurgical technologies. However, it is his earlier treatise published in 1546 that is of greater inportance to systematic mineralogy and its consequential history.

Agricola's *De Natura Fossilium*[995] employed physical properties as the basis of mineralspecies identification; inorganic nature was first split into 'fluids and vapors' and 'fossils,' and the latter were further divided into 'simple fossils,' composed of one kind of material (i.e., gems, metals, earths, and stones) and 'compound fossils', composed of two or more kinds of materials (e.g. metal ores, conglomerates). Individual species were identified and defined by their distinctive properties.

*De Natura Fossilium* anticipated the future of mineralogy, as Agricola influenced by past authors and incorporating his own independent ideas, based his descriptions on the external characteristics of the minerals. This is not suprising, because when the book was written little was known or even imagined of modern chemical theory. It is therefore appropiate that the first mineralogical system, which can be termed modern, would find its foundation in the tangible, physical properties of minerals. The advantage being that species could be readily identified in hand specimens. The value of this system is minor, however. Agricola had learned mineralogy from the practical experience he gained on visits to the numerous mines of Saxony; therefore, it is little suprise that his scheme to divide minerals is likewise practical and not scientific. His classification is subdivided into five principle classes, as follows:

A. *Terrae*. 1. Agricolarum, pingues et solutas, ex. humus. 2. Figulorum, pingues et spissas, ex. chaulk. 3. Fullonum, pingues et siccas, ex. pijpaaarde. 4. Pictorum et artificum, macras, ex. kalkaarde, krijt. 5. Medicorum, ex. bolus, tripel (glebas alanas).

B. *Succi concreti*. 1. Sal et nitrum. 2. Alumen et vitriolum. 3. Chrysocolla, Caeruleum, etc. 4. Auripigmentum, Sandaracha. 5. Sulphur, Bitumen, etc.

C. *Lapides*. 1. Stricte sic dictos, mediae naturae inter terram, lapidem et metallum, ex. gypsum, mica. 2. Communi nomine sic dictos, ... waartoe verschillende fossielen worden gerekend, ex. lap. judaicos, ammonitas, verder among others fluorite. 3. Gemmae, including opal and agate. 4. Lapides magnos polituranitentes, ex. marble. 5. Saxa, ...waartoe o.a. verschillende vulkanische asschen behooren.

D. *Res fossiles*, ex. stibnite, pyrite.

E. *Metalla*, including bismuth.

To make the divisions of the classes, Agricola employed the manner of origin, such as is obvious for the 'succi concreti,' those which are created from liquid. The earths are divided by their uses. The remainder are arranged after the author's many new ideas, for example, he places bismuth first among the metals.

Agricola's system was not destined for longevity, because no complete mineralogical system could be based solely on the physical properties of minerals. Its importance lies in the fact that it was the first to show a modern mineral classification, and its influence was quickly felt. In the works that preceeded Agricola, few were able to bring order to the chaos of mineralogy. Yet

[995] Add info here ...

after Agricola, authors attempted through imitation or originality to organize minerals in to systematic arrangements.

### 9.4.3 Gesner

Conrad Gesner proposed an alternative mineral classification in his *De Rerum Fossilium*. Gesner divided all fossils into fifteen classes on the basis of external shape. The first class included all euhedral geometrical shapes such as pyrite cubes and other regular crystals. The second class was comprised of "forms like heavenly bodies," such as starshaped crinoid columnals. Other classes included "like things from the sea," "like parts of trees," and "like parts of animals." Given the varied forms of many minerals such a classification proved difficult to implement, but it was one of the first systems to emphasize the importance of mineral form.

His book on Fossils, Stones and Gems was written in the year of his death, while his great work on plants still remained unfinished. It was the last of his books which appeared before his death. It is a work of small octavo size, consisting of 169 leaves with a dedication and a preface and is stated by Gesner to be the first book on the subject of which it treats to be illustrated by cuts and figures. This is substantially correct, although the De Re Metallica by Encelius, which was published at Frankfort in 1551 contains four small wood cuts, two of shells and two which represent varieties of aetites, all of which are reproduced in Gesner's work.

Gesner's book bears the following title: De Return Fossilium, Lapid um et Gemmarum maxime, figuris et similitudinibus Liber: non solum Medicis, sed omnibus rerum Naturae ac Philologiae studiosis, utilis et jucundus futurus, Zurich, 1565. It is one of eight short works on various mineralogical subjects by different writers assembled in one stout volume of small octavo size having apparently been brought together by Gesner. This composite volume was published in Zurich in 1566.

This book Gesner states, was written offhand and rapidly as a pleasure and recreation, and was intended to stimulate and encourage all students who were interested in minerals, fossils and stones to continue their studies of these objects and to communicate with him concerning any points on which he was in error and to indicate any directions in which this book should be extended and elaborated, since he intended later to write another and larger work in which the whole subject would be treated more fully and completely. He hoped that the illustrations in the book would be of assistance to such students and refers to the difficulty which he experienced in giving adequate pictorial representation of minerals and rocks, as compared with animals and plants, especially without the aid of color, which in the present case he was unable to employ.

One of the first requirements in the presentation of a satisfactory System of Mineralogy was, of course, the selection of some adequate basis of classification. The writers of old lapidaries, as has been stated, arranged the minerals in alphabetical order according to the initial letter of their Latin names.

The method which he adopted was quaint and interesting the explains it in the dedicatory epistle to his book De Rerum Fossilium. . .Figuris. He says that he is unwilling to adopt an alphabetical arrangement as most of the earlier writers had done, since he considers this method to be commonplace and trivial. Nor will he take substance as a basis of classification. He states that he intends later, if an opportunity pre-sents itself, to write a second book in which he will describe all stones and metallic substances, explaining at the same time the derivation of their names. In the present work Gesner says he wishes to draw especial attention to the figures with which the book is illustrated and goes on to say that he always experiences a feeling of delight in the contemplation of the forms and shapes in which the Creatress Nature has expressed herself pictorially as it were with the brush of a painter. And he intends in the discussion of these fossils to follow in the steps of Nature herself and adopt a classification based on the forms displayed by her.

Taking first those fossils whose forms are of the simplest character resembling lines, angles, circles or allied forms, as seen in the heavens or in the elements, he will pass on to consider

those which bear a resem-blance to more complex forms, descending by degrees from the heavens and celestial things to the earth and things which live upon or are nourished by it, and consider those fossils which in their form resemble plants or animals or parts of these.

Following this method of classification the members of the mineral kingdom are brought into one or other of the following 15 classes.

1. Those whose forms are based upon, have some relation to, or suggest the geometrical conception of points, lines or angles. This includes all transparent or translucent minerals such as sunstone, within which there are minute and more or less rounded inclusions; also minerals upon whose surface little dots are seen, together with rounded concretions of all sorts and fossils having a more or less rounded shape. Also bodies like pumice stone, whose surface shows depressions often rounded in shape. It also includes asbestos, natrolite and all fibrous or acicular minerals also all minerals whose forms display angles, such as cubes of pyrite, "Juden-stein," hexagonal prisms of quartz, pologonal columns of basalt and so on.
2. Those which resemble or derive their name from some heavenly body or from one of the Aristotelian elements. This class includes moonstone, selenite, carbuncle, aquamarine, opal and agate which often display little pictures of rivers or landscapes, also diamond which is clear and transparent like air, and Asterias (the separated elements of the stalk of a Mesozoic Coral) which in transverse section displays the form of a star.
3. Those which take their name from something in the sky. This embraces the fossil Echinoderms, as well as the Palaeolithic and Neolithic stone axes and other weapons, all of which were believed to have fallen from the sky. Also certain minerals and stones which display smoke-like markings or appearances which resemble clouds.
4. Those which are named after inanimate terrestrial objects. In this class are pisolite (peastone), chrysolite (after gold), iron ores, lead and other metallic ores.
5. Those which bear a resemblance to certain artificial things belemnites (like darts) stalks of Palaeozoic crinoids (round like wheels).
6. Things made artificially out of metals, stones or gems. Rings, whetstones, seals, vases, the Mariner's Compass (made from magnetic iron ore), writing tables, lead pencils. He gives here the earliest picture of a "lead pencil." This was apparently metallic lead not "black lead" qr graphite.
7. Those which resemble plants or herbs, plants turned into stone, (Encrinus 'the stone Lily') stones which have the form of apples and other fruits.
8. Those which have the form of shrubs Rhodites (which bear a resem-blance to a rose), siliceous minerals and rocks which have branching coral-like forms.
9. Those which resemble trees or portions of trees. Trees which have been petrified and coal plants.
10. Corals.
11. Other sea plants which have a stony nature. Lithophyton and others.
12. Those which have some resemblance to men or to four-footed animals, or are found within these. Native silver in hair like forms, carnelian (blood stone), hematite, calculi, bezoar stones, ocellus, glossoptera (like tongues) and others.
13. Stones which derive their names from birds.
14. Those which have a resemblance to things which live in the sea. Fossil fish, glossoptera (sharks teeth), orthoceras, pecten and other sea shells.
15. Those which resemble insects or serpents. Ammonites, ophites, and others. Here he describes the first nummulites from the Paris Basin and refers them to the ammonites.

It is interesting to note that some fossils which resemble the remains of living animals he considers to be such, while others in which the resemblance is less distinct he thinks may not be such, but may have originated through some forces at work within the earth itself. It will be noted that in each class or division there are brought to-gether a most miscellaneous group of bodies which have no relation to one another other than that of a supposed resemblance in shape. The grouping is interesting however, as presenting one of the very earliest attempts to classify the members of the mineral kingdom.

As Gesner died immediately after this book was printed he never wrote the second work which, as above stated, he intended to prepare later. This little oook is of especial interest in that it presents a picture in miniature of the mineral kingdom as seen through the eyes of the greatest maturalist of his time. It marks a departure from the

medieval lapi-daries in that it says little or nothing concerning the miraculous pro-perties and "virtues" which had been attributed to minerals but endea-vours rather to describe the characters by which they may be recognized. It is in fact a more or less popular handbook for amateurs and others, written to arouse an interest in "fossils" and to encourage students to collect and study them.

With regard to the sources from which it is drawn, it is seen to be a compilation of the observations and opinions of other men, supplemented in a number of instances by those of Gesner himself. He owes much to Kentman and he borrows largely from Agricola, although he does not acknowledge his indebtedness to the latter writer as fully as he ought to have done.

### 9.4.3 Kentmann

Soon after Agricola others began to compile quanities of mineralogical information. Of these, Johann Kentmann is one example for illustration. He assembled a superior arrangement and nomenclature of the collection he described in a tract titled *Nomenclatura rerum fossilium*, which appeared in 1565. Something his system concerns, is yielding to demolishing in part Agricola's system. In place of the five main divisions, he makes four. Among the 'De res fossiles' he brings a large number of the metals [see synopsis].

The increased desire for collecting gave, however, no great increase in knowledge to its followers. Indeed, multitudes of systems arose, a few on completely original foundations, but the majority repetitions of the past, and usually based wholly or in partly on Agricola.

The study of the various outward characteristics employed by Agricola was still very scanty and especially in the beginning one still had little concept of their relative value. Consequently everything of minor variation in the species caused a misclssification of the mineral; for example, minerals of one kind but dissimilar in character became separated, while very diverse kinds were collected together. In essence, a great confusion reigned among all mineralogical subjects of this period.

**[SEE ST. CLAIRE 1966 PAGE 41.]**

### 9.4.9 Caesalpinus

Andreas Caesalpinus court physician for Pope Clemens VIII, wrote in 1596 at Rome a work *De Re Metallica*,[996] wherein he gives an independent division in orders and classes. He thought that all minerals are derived either from water or from the earth, and divided them according to their solubility in water and oil, and according to their fusibility. Meanwhile, the earths are subdivided after Agricola's method, as follows:

A. *Humore solubilia.*
   I. Terrae. a. Agricolarum, gracilis et pingues, ex. humus. b. Figulorum et plasticorm, tenaces, ex. clay. c. Fullonum, ex. ...tripel.... d. Pictorum, ex. ...krijt.... e. Medicorum, ex. armeniam ...Armenische steen....
   II. Salia. a. Sal fossile, commune. b. Nitrum. c. Alumen. d. Calcanthum, ex. melanteriet.
B. *Oleo solubilia*, ex. sulphur, ...auripigment....
C. *Illiquabilia.* Lapides.
   I. Saxa, quae ingenti mole oriuntur, nec poliri possunt, alia ob insignem duritem, alia ob mollitiem, ex. gypsum.
   II. Marmora, mole pariter majora, sed quae poliri possunt, ex. marble.
   III. Gemmae, parvae, rarae, insigniter durae. a. Pellucidae vel splendentes, ex. topaz, diamond. b. Opacae, ex. onyx.
   IV. Lapides, qui discedunt a gemmis laevore, splendore et duritie. a. Ex plantis et animalibus nati, ex. belemnitae, judaicus. b. In animalibus generati, ex. bezoar. c. In fibris saxorum aut metallix, ex. talc.
D. *Liquabilia*, ex. gold, tin, silver.

As one sees, this system was mistaken in the division of the earths. Noteworthy is also how Caesalpinus and even later on Schwenkfelt still capture the influence of the Greeks, Aristoteles and Theoprastus; they are discussed and partially followed. Moreover a great difficulty during this time was that mineralogy had yet to be acknowledged as an independent science. According to Keferstein, Torbern Bergman in 1768 was the first to gain the postion of professor of mineralogy. Before that time, the science was incorporated into chemistry, then physics, then zoology and

[996] Add information here

botany, then practical mining or metallurgy, then amateurs, who occupied themselves with mineralogy indirectly from a study of nature in general.

## 9.5 The Seventeenth Century

### 9.5.15 Boëtius de Boodt

Anseimus Boëtius de Boodt, who was particularly interested in gemstones, included the subjective properties of rarity and beauty along with size, color, and hardness.

His *Histoire Gemmarum et Lapidum* authored by Anselmus Boëtius de Boodt first appeared in 1609.[997] It is essentially a handbook of the lapidary art, including discussions of the machines, tools, and methods used. It is divided into two principal books. The first of which considers the various physical properties of minerals. The second describes about 130 mineral substances recording for each information about the various names it is called by, physical properties, occurances and approximate cost. The work surpasses almost all previous books, however, by being more circumspect, more detailed, more exhaustive and more systematic in its treatment.

Like Agricola, Boodt avoided giving a simple alphabetical list of the mineral substances he describes. Instead Boodt proposes two classification schemes based on physical properties. These are outlined in two tables included in the treatise. Table I divides the minerals as follows:

A. Lapis alius [All stones].
I. Paruus [Small]. a. Rarus [Rare].
1. Durus [Hard].
i. Pulcher [Attractive]. a. Opacus [Opaque]. b. Diaphanus [Transparent].
ii. Turpis [Unattractive].
2. Mollis [Soft].
i. Pulcher [Attractive]. a. Colora [Colored]. b. Figura [Shape].
ii. Turpis [Unattractive]. a. Frequens [Common]. 1. Durus [Hard]. 2. Mollis [Soft].
II. Magnus [Large]. a. Rarus [Rare].
1. Durus [Hard].
i. Pulcher [Attractive]. a. Opacus [Opaque]. b. Diaphanus [Transparent].
ii. Turpis [Unattractive].
2. Mollis [Soft].
i. Pulcher [Attractive]. a. Colora [Colored]. b. Figura [Shape].
ii. Turpis [Unattractive]. b. Frequens [Common]. 1. Durus [Hard]. i. Pulcher [Attractive].
ii. Turpis [Unattractive]. 2. Mollis [Soft].

This first system is based principally on the physical properties of color, shape, hardness, transparancy and rarity. Boodt recognized however that many other variations to this table could be created using these same properties. After all, any classification is just a general method for expressing relationships between things, and Boodt considered the physical properties to be accidental to the mineral species and not the essential ingedients needed for a proper classification [See: St. Clair, p. 29, 71]. Consequently, he said that his opinion as to a correct classification might differ from someone elses. He invited, therefore, others to create their own schemes by rearranging the characteristics of the divisions [See: St. Clair, p. 29 72). To further push the point he included a second classification table that lists the following scheme:

REDO CLASSIFICATION - BASE IT ON ST. CLAIR APPENDIX

A. Lapides ex animatis [Animate Stones].
I. Volatilibus [Volitile]. ex. alectorius, and stones found in the stomach of chickens.
II. Aquatilibus [Aquatic]. a. Pisicibus [From fish]. b. Insectis [From insects].
III. Terrestribus [Terrestial]. a. Vel plantis [From plants]. ex. coral. b. Vel Animalibus [From animals]. c. Vel homine [From Man]. d. Vel brutus [From beasts]. ex. bezoar. e. Vel insectis [From insects]. ex. limacius.
B. Lapides ex inanimatis [Inanimate Stones].
I. Ardentes [Flammable]. ex. succinum.
II. Figura mathematica [Mathematcally Shaped]. ex. basalt.
III. Figura rei animatae [Animate figured].
IV. Figura rei inanimatae [Inanimate shaped]. ex. stalactite.
V. Nulla figura [No certain shape]. a. Diaphani [Transparent]. ex. emerald. b. Opaci [Opaque]. ex. agate. c. Vel turpes [Attractive]. ex. marble.

[997] Add information here

Though the properties used to distinguish the stones are essentially unchanged from Table I, a new classification has been derived for Table II. Boodt used this to support his contention that no true classfication could ever be based totally on physical properties. Although Boodt's tables were a considerable improvement over Agricola's initial attempt, neither work could be called a thourogh system.

### 9.5.16 Aldrovandi

In 1648, *Museum metallicum in libros IV distributum* by Ulysses Aldrovandi, the division of the stones is especially strange.

**[SEE St. Claire p. 42]**

A. Terrae. I. Agricolorum. II. Figulorum. III. Fullonum. IV. Pictorum. V. Medicorum. VI. Compositae. VII. Terris adfinia.

B. Succi concreti, ex. ocher, sulfur, stalagtite.

C. Lapides. I. Communi nomine sic dicti. II. Qui attriti succum emittunt. III. E variis locis nomen habentes. IV. Magores et Saxa. V. In corpore animantium geniti. VI. Semiperspicui. VII. Perspicui.

D. Metalla.

* * * * * * * * * * *

Ulisse Aldrovandi (Ulysses Aldrovandus) (Bologna; 1520-1605) professor of philosophy and medicine in Bologna, spent his means in publishing several large folio volumes of a work on natural history at Bologna and left a mass of manuscript material, some published subsequently. He died in poverty in a hospital;7 some of his manuscripts and botanical collections were burnt as fuel. His published works comprise (all f °, Bologna): Ornithologiae Libri XII, 3 vols, 1599-1634 De Quadrupedibus Solidipedibus, 1616 Quadrupedum Omnium bisulcorum Historia, 1613,1621 De Quadrupedibus digitatis viviparis et . . . oviparis, 1637 De Reliquis Animalibus, 1606 De Piscibus et Cetis, 1613 De Animalibus Insectis, 1602, 1638 (767 pp.) Serpentum et Draconum Historiae, 1640 Monstrorum Historia, 1642 Musaeum Metallicum, 1648.

1668, but does Another volume on trees, Dendrologia naturalis, was also issued, f ° not properly form part of the set.

Several of these were republished in Frankfurt (1616-29; Dendrologia 1671, 1690). Aldrovandi's books are scholarly and useful; the one of direct interest to us, which is often cited, is Musaeum Metallicum, compiled some forty years after the death of Aldrovandi by Bartholomaeus Ambrosinus from a manuscript Geologia ovvero Fossilibus, which is said to use the name 'geology' for the first time in its modern sense. The work is divided into four sections: on metals, earth, concrete juices (succi concreti), and stones (minerals, rocks, and fossils). It includes the medicinal properties of rocks, minerals, and gems. In most cases it gives synonyms, places of occurrence, uses, mythology, medical virtues, etc., classical, medieval and modern authors being quoted. It is pos-sible that some additions were made by the editor.

Aldrovandi1 says astrologers and chemists (chymici) associate the planets with metals and parts of the body, but this idea had been exploded by Scaliger; yet he says later that the moonstone suspended from the neck by a thread of silver (a metal associated with the Moon) produces the same effect as the Moon.2 The bezoar stone, which is Jovial, if carved with the image of a scorpion when the Moon is in Scorpio, resists the stings of scorpions.3 Recent physicians (medici) infer from the fact that gold is best purified by antimony that man the microcosm may be purged of noxious humours by antimony, and this is con-firmed by experience.4

Paracelsus had reported that a magnet was strengthened by repeatedly igniting it and quenching it in an oil made from crocus of iron and the best steel, but Baptista Porta found it lost its magnetism, and had also found false the statement that a magnet ceases to attract iron if anointed with garlic or in presence of a diamond, unless the latter was counteracted by goats' blood.5 Yet Porta had obtained the gem from the head of a toad by putting it on a purple cloth and angering it by blows.6 Aldrovandi was shown eggs laid by a cock but he doubted if they would hatch basilisks.7

Aldrovandi's works contain a great store of ancient and modern superstition and occultism (rather over-emphasised by Thorndike), and he was in trouble with the Inquisition in 1549 and 1571, but escaped imprisonment. In 1615 the government of Bologna petitioned Rome for



On the History of Mineralogy & Crystallography from Beginnings through 1919
by Curtis P. Schuh, Tucson, AZ—Edit Draft. [1200dpi]
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the return of some of his books, but without effect.1 Aldrovandi set the fashion for modern authors in com-piling long lists of authorities but omitting to mention those mainly used, e.g. Conrad Gesner on animals.2

### 9.5.17 Jonston

One of the best systems of this period belongs to the doctor, Johannus Jonston, which was published at Leipzig in 1661 in *Notifia Regni Mineralis seu Subterraneorum Catalogus*. This system finds its foundation in the previous work of Agricola, and like all scientific investigators, Jonston attempted to improve the previous methods with his own ideas. Consequently, new combinations not seen before, arise. For example, alabaster is grouped with basalt, because it properly fits with large, opaque stones. His imagination was likewise very active about the figured stones. His division is as follows:

A. Terrae [Earths]. I. Ignobiles [Non-precious]. a. Agricolarum. b. Figulorum et fullonum. II. Mediae [Medium]. III. Nobiles [Noble], medicorum. IV. Affinis terrae, ex. volcanic ash.

B. Succi concreti [Solidified Juices]. I. Macri [Lean] ex. saltpeter. II. Pingues [Fat].

C. Bitumina [Resins]. I. Liquida [Liquid]. ex. sulphur, petroleum. II. Concreta [Solid]. ex. asphalt. III. Lapidosa [Stone]. ex. coal.

D. Lapides [Stones]. (By the divisions used by de Boodt). I. L. fossiles. 1. Non figurati. a. Diaphani. Clari [Transparent. Clear]. ex. diamond, ruby, sapphire, emerald, topaz, smokey topaz. b. Semidiaphani [Semitransparent]. ex. jasper. c. Opaci [Opaque]. ex. malachite, hematite, gypsum, alabaster, basalt. 2. Figurati [Figured]. a. Coelesti ex. cat's eye. b. Corporum sublunarium ex. stalactite. c. Vegetabilum ex. coral. d. Animalium [Animals]. including fish, birds, beasts, etc. II. L. animalis [Animals]. ex. bezoarstone.

E. Metalla [Metals]. I. Nativa [Native]. ex. iron, lead. II. M. sui generis ex. bismuth, mercury. III. Metalla adfinia.

The whole of mining science, such as the scholars of the end of the XVIIe century included/understood it, finds its expression succinte in the opuscule of Jean Jonston, published in 1661 with Leipzig, heading Notifia regni mineralis seu subterraneorum catalogus. Coming from a Scottish family established in Poland, Jonston said itself one, Scoto-Polonus ". Born in Szamotuly in 1605, it took its doctorate of medicine in Leyde; the major part of its life ran out in Leszno at the court of Boguslas Leszczynski, of which he was the doctor and the tutor. It starts its treaty by a review of the gases which are released from the ground and by that of water which results from this. It distributes the matters of mines themselves in five groups, namely: 1), earths, 2) solidified juices, 3) resins, 4) stones, 5) metals. We cannot occupy us here of the detail of the classification of Jonston. It is based on qualities less essential, external, like state of aggregation, degree of limpidity, color. It could not be of it differently. At that time, analytical chemistry was hardly at its beginnings;the bases of systematic reasonable of minerals did not exist yet.

It should be believed, according to the final words of the opuscule of Jonston, that it conceived it like a draft of a broader work. But this work never appeared.

As is obvious from the earths, Jonstone employed precious and non-preciousness. This remained the fashion for a long time, but similtaneously produced great disparity in classifications. Commonly precious stones are placed among the noble metals.

### 9.5.19 Bockenhoffer

Another truly remarkable system of the era is Johann Joachim Bockenhoffer's, which appeared in *Museum Brackenhofferianum*.[998] Here the stones are classified according to locality and the manner of origin: those, which fell from the air, those, which are excavated from the caverns of the earth, those, which one finds scattered upon the bottom of rivers, those, which produce fluid, and those, which originate from animal secretions. The system is as follows:

A. Ad Metalla refert Metallis adfinia. I. Naturalia, quae in Montibus nascuntur ex. galena, mica, pyrite. II. Artificialia, extra Montes ex. molybdenum.

B. Lapides enumertat. I. É Terrae Latebris Effossos ex. marble, dendrites. II. É Meteoris Delapsos [Fell from

[998] Johann Joachim Bockenhoffer., *Museum Brackenhofferianum*, 1677.

the air]. ex. cerauniam. III. É Fluminum Fundis Extractos [Fluid is extracted]. IV. Ex Animalibus Extractos [Extracted from animals]. V. Nobiles Gemmas [Precious gems]. ex. diamond, ruby. VI. Ignobiles Gemmas [Non-Precious Gems]. ex. oculum mundi, beli, felis, margaritas.

C. Ad Mineralia Media connumerantur Terrae ex. sulphur, salt.

This system shows well some of the strange ideas that had to be tested and either accepted or discarded in the path to a correct classification. Its duration was not long, but it is an example worth noting because it is typical of the period that the greatest difficulty was understanding that a good classification needs specific and unique indicators to distingush its parts. Starting toward the mid 17th century and extending well into the 18th century, mineralogy became heavily influenced by developments in chemical theory. The physical and chemical properties of matter were beginning to be discovered. This lead to a new theoretical framework not concieved before being erected, and some naturalists choose to place minerals in its structure.

This catalog describes the fine library and art and natural history collections of Élie Brackenhoffer [see note below]. The author follows Brackenhoffer's physical layout by dividing the collection into Fossil, Vegetable, Animal and Artificial. Every object found a place under one of these heads, and the text reveals most of his natural history specimens were mineralogical, which were consequently listed under Fossil. The divisions of this class included metals, stones, and mineralia media. The metals were divided between natural and artificial, while the subdivisions of the stones show the uncritical character of the mineralogy of the time. These were classified into: Lapides majores molles, stones taken from animals, meteoric stones, Lapides fossiles minores, Silices minores, petrifications including petrified wood, the petrified molar of an elephant, gems and precious stones, and corals. The mineralia media included the earths and sulphur. Among the animals a crocodile can be found. The vegetables stood by themselves. The primary division of Artificial items was into objects made of wood, glass or ivory, while other groupings included pictures, gold and silver work, works of art in marble, wax and other materials, antiquities and coins.

This is a luxuriant volume printed on fine paper stock in red and black throughout with marvelous typography. Although very rare, it attracted enough notice to have an abstract reprinted in Michael Bernhard Valentini's *Museum Museorum*, Frankfurt am Mainz, 1714, vol. **2**, appendix XX, pp. 69-81. In addition, several letters in Franz Ernst Brückmann's *Epistolæ Itinerariæ* reference Brackenhoffer's collection (*see*, *Epistolæ*, vol. **1**, 39-47, 57-60, 64-65, and 81-84).

### 9.5.21 Becher

Among the first to use a chemical basis in classifing minerals was Johann Joachim Becher professor of medicine at Mainz and court physician for the elector of Mainz and Bavaria. In the *Physicae Subterraneae*[999] he attempts to classify plants and animals as well as minerals into a new system based on his own theories of chemistry. The fundemental theorm was that all substances could be reduced to three earthy principals and water. These principals, which carried various names, can be classified as the vitrious earth, the combustible earth, and the fluid earth. [St. Clair p. 90, 2].

Based on the christian doctrine of a supreme triad, Becher believed that trinities of things were highly significant. In each of his classifcation systems he used the trinity as a base; therefore, the mineral system he proposed is formed of three groups: Simplicia, Composita, and Decomposita. Each of these in turn is divided into three groups. [St Clair, p. 92, 3]. His system for minerals is outlined below: [From St Clair, p. 91]

A. Simplicia. 1. Terra prima 2. Terra secunda 3. Terra tertia.

B. Composita. 1. Terrae [Earths]. a. Arenae [Sand]. b. Limi c. Hortensis 2. Lapides [Stones]. 3. Metalla [Metals]. a. Minus perfecta (sive mineralia) b. Perfecta (sive metalla).

[999] Add information here ...

C. Decomposita 1. Terrea a. Sicca i. Pinguia ii. Macra b. Liquida i. Oleosa ii. Aquea 2. Lapidea a. Pinquia b. Macra c. Mineralia d. Salina e. Aquea 3. Metallica a. Sicca i. Pinguia ii. Media iii. Macra b. Liquida.

The threefold division of substances - prominate in later classifications - is directly attributed to Becher. Many subsequent researchers grouped minerals according to whether they vitrified, calcined, or were unaffected by fire, but Becher was the first. For example, of sand he said: [St Clair, p. 92].

* * * * * * * * *

Johann Joachim Becher for his system followed Johnston and organized his minerals according to external characters. As Johann Gottschalk Wallerius mentioned, ¡KOBELL, p. 59¿ the beginner in the study of mineralogy was not freighten off, at the division he brought into application the chemical characters. (Physica subterranea. 1664. Lib. 11, sect. VI, cap. 1.). Becher differentiated four classes.

A. Terrae - sand, humus, ...mercurialische..., (Lutum, Limus, Argilla).

B. Lapides, which he said could be determined by their behavior in fire, in that such minerals are transformed into either chalk or glass.

C. Mineralia. Here the metals are mentioned. In general, the word 'mineral' is used to define any object dug from the earth. The author notes that the word mineral is derived from the ...hebraischen... 'Metil', which 'found' ...giessen... means. The metals are complete: gold, silver, copper, iron, lead, tin, antimony, bismuth, zinc, marcasite. Included as 'decomposita' are cobalt and manganese, which is known from the mineral pyrolusite.

The 'Decomposita', which builds a particular division, are different species: When an Earth is mixed with a Metal or a Stone or when different metals are mixed together then there is created a 'decomposita'. He differentiated in this division three classes that are respectively called earthy, stony and metallic decomposita.

In the first he counted the Bitumina, sulphur, pumice, and salt, rock salt, salt peter and mineral water.

To the second belong items of a dissimilar chemical nature: peat, slate, quartz, alunite, borax, and common rock, in which metals are produced, etc.

To the third class belong: arsenic, realgar, orpiment, cinnabar, mercury, proustite-pyrargrite, etc.

He discusses in considerable detail the properties, which were considered in the organization of the minerals and generally these are illustrated by hardness, flexibility, conductivity of heat, transparency, etc.

¡KOBELL, p. 60¿ In reference to the 'vollkommen' (perfect or complete) or 'schlect' (bad or ill) he said, it is to be noted, that nature is not ill and God created everthing perfect. What one names perfect are so named with all sorts of consideration like the proverb said: A precious stone is worth only as much as the fool is willing to offer in exchange.

Another system is given in the 'Pharmacopaeus sui temporis clarissimus' of Ferrandus Imperatus [@], an Italian. He split the earths into five genera: 1) Agricolarum, 2) Plasticorum et Architectorum, 3) Fusorum, 4) Pictorum et Fullonum (Fuller's earth), 5) Medicorum. The stones he separated into 1) Precious stones, 2) Figured stones, 3) Those that burn to gypsum, 4) Those that yield micaceous plates, 5) Those that can be transformed to lime, 6) The vitrifiable, and 7) Sandy.

### 9.5.23 Hiärne

Urbane Hiärne was an industrious and highly intelligent man who valued above all else the use of his time.[1000] He is also credited as the person who raised the curtain on Swedish chemistry. This was no small accomplishment, as chemical investigations of the time invariablly lead to an intense pursuit of the allied subject, mineralogy. It was after his appointment to head the Laboratorium Chymicum[1001] that Hiärne became involved

[1000] Bertil Åberg, "Urbane Hiaerne. The first Swedish Chemist," *Journal of Chemical Education* **27**, p. 336 writes: "His industrious was astounding and he had a wax tablet on which he wrote down the ideas he got while lying awake in the night. Over the door to his study he had written: "Friends are thieves who steal our time, worse than others not being able to restore the stolen property."

[1001] Laboratorium Chymicum was established in 1683 by the royal decree of Charles XI. After extensive travels abroad, Hiärne argued that no enlightened goverment could but take an interest in chemistry.

in the practical aspects of chemistry, especially in conjunction with mining and minerals. In particular, he sought ways to exploit the mineral resources of the Swedish kingdom.[1002] To advance towards this goal, Hiärne published *Een kort Anledning till Åtskillige Malm-och Bergarters*[1003] *Stockholm: Wankijfs Änckia, 1694. 4°: 12 unnumbered leaves.* which because it was "written not for the learned but for searchers of ore, [the work] unfolds practical views on the subject."[1004] , "A leaf from the history of Swedish natural science," in *Nature* **21** (April 1, 1880), p. 520.Thus the author does not make sweeping theoretical statements but relies upon his own keen sense of observation. In fact, a glance at the classification employed by Hiärne shows nothing outstanding, but later mineralogists would point to this work as an important development in mineralogy.[1005]

Table 1, which condenses Hiärne's method, lists six principle categories: earths, stones, metals, semi-metals, salts, and sulphurs, essentially echoing previous classifications.

The combination of chemistry and mineralogy continued shortly thereafter with a Swedish chemist. Urbane Hiärne published in 1694 the mineralogical system in his "Kort anledning til ...".

A. Water.

B. Aardsoorten, ex. humus, turf.

C. Steensoorten. I. Van gebergten, ex. limestone, gypsum, silicates. II. Gewone steenen, ex. quartz. III. Gewone nuttige steenen, ex. mica. IV. Gevormde steenen. V. Steenen, in dieren gevormd. VI. Edelsteenen, ex. marble, jasper.

D. Metalen, ex. gold, silver, lead, mercury.

E. Halfmetalen, ex. antimony, bismuth, haematite, basalt, asbestos.

F. Zouten, ex. vitriol.

G. Zwavelachtige, ex. sulfur, petroleum.

## 9.6 The Eighteenth Century

A debate over the true or 'natural' basis for mineral classification developed in the eighteenth century and would pervade the mineralogical literature. Naturalists observed the great variety of forms exhibited by individual species and so some rejected crystal form as a basis of classification in favor of chemical or physical properties. Other scientists took a different view speculating that form and only form should be used for the classification of minerals.

### 9.6.20 Woodward

John Woodward *Fossils of all kinds digested ...* London: 1728 and An Attempt towards a Natural History ... London: 1728. John Woodward's system belongs to the best. He gives a great deal of consideration to the appearance, but by doing so his classification is sometimes sent into confusion.

A. Earths. I. Those which feel greasy to the touch. a. Those which cling to the tongue, ex. clay. b. Those which do not cling, ex. slate. II. Those which feel dry and roughto the touch, ex. ochre and marl.

B. Stones. I. Those which anticipate/pervent. a. Loose and coarse grained, ex. sandstone. b. Loose and fine grained, ex. sandstone. c. Hard and fine grained, so that they are able to take a polish, ex. marble and alabaster. II. Those which one finds in small pieces. a. Not harder than marble. i. Of unlimited form and structure, such as all kinds of round stones. ii. Of unlimited form, but at the same time of determinable structure such as bladed, radiating, angled, shale-like, ex. gypsum and mica. iii. Of limited form and with determinable structure, ex. stalactite. b. Harder than marble. i. Non-transparent, with either a color or a , ex. . ii. with varible or lasting color, ex. . iii. Transparent, colored

[1002] A.F. Cronstedt"Åminnelsetal öfver H.T. Schffer," in *Lars Salvius*. Stockholm: 1760. pp. 15–31. [Translation taken from Weeks, *Discovery of the elements*. New York: 1945, p. 71] "Hiärne in his lifetime pursused chemical research most zealously. With all his creative genius and his desire to support Cartesian natural science with chemical arguments and conclusions, he still did not fail to consider the practical use which industry could demand of it. With the support of the authorities, he therefore occupied himself with the testing and investigation of sustances from all realms of nature and all parts of the country."

[1003] U. Hiärne, *Een kort Anledning till Åtskillige Malm-och Bergarters Mineraliers Wäxters och ineraliers*, Jordeslags sampt flere sällsamme Tings effterspöriande och angifwande Esster Kongl. May. Allnådigste Behag Stålt till Alla uti Küket som kunna hafwa Luft at låta i Dagzliuset komma hwad som i hwar och en Ort kan finnas.

[1004] A.E. Nordenskiöld

[1005] M.v. Bromell, M.v. *Mineralogia et lithographica Svecana*. Stockholm & Leipzig, 1740. p. 5 recto said: [add translation of what Bromell said from St. Clair, p. 95]

or uncolored, among which the precious stones are placed.

C. Salt. I. Appendix, ex. sulphur and arsenic.

D. . I. Liquid. II. Fixed.

E. Minerals (Ores). I. Liquid, ex. mercury. II. Fixed and , ex. cinnabar and cassiterite.

F. Metals.

G. Petrifactions, divided the same as Scheuchzer.

### 9.6.21 Henckel

Johann Friedrich Henckel. This illustrious "Scheidekünstler" authored diverse works, in whcih he likewise took-p diverse classifications. In the maintance system is employed a good classification, by paying attention upon the behaviour in fire and the chemical composition. He can thus be called a predessor of Cronstedt.

**[SEE St. Claire p. 127]**

Henkel in his work, Idea generalis de lapidum origine, per observationes, ... 1748 followed Woodward and Scheuchzer in the division of the stones and earths.

I. Ongevormde, ... II. Regelmatige ... III. Regelmatige ... IV. Die, welke gelaagd ... V. Die, welke in afz. stukken ... VI. In afz. stukken zonder ...

In his work: *Mineralogia Redivius* (1747) the division is as follows:

A. Water, divided into superterrestial and subterranean.

B. ...

Although Wallerius is in this period, because of his system published in 1747, he is nevertheless placed in the subsequent time because of his contributions there.

### 9.6.23 Pott

Johann Henrich Pott was a noted chemist who at the request of the King of Prussia performed thousands of tests in a systematic search for the secret of Meissen porcelain. His *Chymische Untersuchungen*,[1006] which resulted from this study of porcelain clay did not attempt to complete systematic description of the mineral kingdom because it excluded fossils, metals, and salts. However it did discuss earths and stones. Pott broke with the ancient tradition that regarded earths and stones as the same material with their apparent difference being defined by differences in hardness. Based upon the results of his chemical experiments, Pott instead distributed the material usually classified as earths and stones into four divisions based on their behaviour in fire. He named the groups alkaline earths (*terra alcalina*, also *calcaria*), gypseous earths (*terra gypses*), argillaceous earths (*terra argillacea*), and siliceous earths (*terra vitrescibilis strictius sumta*). On the quality of Pott's descriptions, these four groups soon became the standard by which the earths and stones were divided in most subsequent systems of mineralogy.

Pott placed the most weight on the behaviour of a specimen when exposed to varying degrees of heat. Since he noted the results in terms of a compositional difference, rather than terms of the physical effects of the heat, as had Henckel before him, shows that Pott had developed a more generalized concept of mineral substances. For example Henckel wrote of a calss of materials that were fused by fire (*fusiles*), where as Pott theorized a compoistional unity for such fusible materials, and classified such material under the heading of gypseous earths (*terra gypsea*).

Having broken from classifying earths and stones based on external characters, Pott showed a new way to frame classification. From his point of view the correct method was to establish the divisions according to compositional principals as shown by chemistry. Although not a new idea, since metals and salts had been separated by their more obvious chemical differences, it was innovative to arrange the earths and stones in this way.

### 9.6.25 Bromell

The status of his chemistry one can judge, by examining several species. For example, asbestos is included among the semi-metals, marble is still only recognized as one calcareous-kind, etc. Yet, Hiärne's system was recognized by his successors as a major advance. He is for example imitated by Magnus von Bromell likewise a Swede, who in 1730

[1006] Need information here

published a system in *Inledning ....* Herein the chief divisions of his predecessor are preserved; the stones he divides appropiately according to the behavior in the fire, in this way:

A. Aarden [Earths]. I. Voor artsen, ex. ...maanmelk, verschillende kleisoorten... II. Voor schilders, ex. ochre. III. Om te polijsten, ex. tripoli. IV. Voor pottenbakkers, ex. porceliane earth. vol. Akkeraarde, ex. turf.
B. Zouten [Salts], ex. salpeter, alum.
C. Zwavelsoorten [Sulphurs], ex. sulphur, coal, amber.
D. Steenen [Stones]. I. Die het vuur weerstaan [Resisting the action of fire], ex. pot-stone, amiant, asbestos. II. Die tot kalk branden [Calcinable], ex. marble, alabaster, cat's eye. III. Die tot glas worden in het vuur [Vitrifying in fire], ex. sandstone, garnet, quartz, fluorite. IV. Vertsteeningen [Petrifications], ex. woods, corals, crustaceous. V. Steenen, in dieren gevormd.
E. Halfmetalen [Semimetals], ex. mercury, arsenic, bismuth, bloodstone, orpiment, pyrite, basalt.
F. Metalen [Metals], ex. gold, silver, copper, tin.

Magnus von Bromell,[1007] a Swede, was to follow upon Hjärne's work with a more comprehensive mineral system. His 1730 work titled *Mineralogia, eller Inledning til nödig kundskap at igenkiänna och uppfinna Allahanda Berg-Arter, Mineralier, Metaller samt Fossilier, Och huru de mäge til sin rätta nytta anwändas*[1008] was based upon the use of a mixture of physical and chemical principals to classify mineral bodies.

Designed as a handbook to help the naturalist recognize and identify mineral substances, especially those found in Sweden, Bromell's Mineralogia is a mineral system that reflects some of the concepts of mineral relationships seen in Becher's and Hjärne's works. In his preface Bromell states the purpose of his book:

> Meanwhile, I am convinced that the kind reader can expect a threefold benefit from this small treatise. In that, first, he can learn therefrom to distinguish and to recognize the principal minerals; in addition, he can learn the proper names of the rocks and ores, also their nature, habit and use. Second, what kind of such useful fossils should be found and located here by us, and finally, third, which metals and minerals have been found here in this kingdom already, and which should still be sought out.[1009]

Bromell subdivided mineral into earths, salts, sulphur and sulphurous rocks, stone, minerals, and semi-metals, and ores and metals. [ADD TABLE HERE] These major divisions parallel those of Hjärne, Woodward, and others, and are a frequently encountered arrangement in early eighteenth century mineral classifications. Bromell's subdivision of the class earths into medicaments, earths used by painters and dyers, earths used for cleaning and polishing, earths used in ceramics, fertilizers, earthy ores, and fuels, resembles Agricola's arrangement of the earths on the basis of what they are used for. Three of the subdivsions of the class stones are fire-resistant stones, stones that calcine, and stones that fuss and vitrify. Bromell wrote:

> One finds innumerable different kinds [of stones], which in consequence of their variable shape, color, uses, value and nature, are differentiated in various ways. They can, however, be best arranged into such that, in an ordinary fire, resist the fire's heat (and from that are called fire-resistant), melt to flux and glass in the fire, or are burned to calx and powder be means of the flames.[1010]

These groups of stones were modeled after the threefold distinction made among earths and stones by Becher on the basis of behavior in fire. Becher's discussion, however, was speculative, whereas Bromell thought his

[1007] Magnus von Bromell (born: 26 May, 1679 at Stockholm, Sweden; died: 26 March, 1731 at Stockholm, Sweden) Bromell was ...

[1008] Add full title here

[1009] Ich bin inzwischen versichert, daß der geneigte Leser einen dreyfachen Nutzen von diesem kleinen Tractat werde erwarten können. Indem er erstlich daraus lernen kan, die vornehmsten Mineralien zu unterscheiden und zu erkennen; nebst denen eigentlichen Nahmen dererBerg-Arten und Malmen, wie auch derselben Beschaffenheit, Gebrauch und Nutzen. Zweytens welcher gestalt dergleichen nützliche fossilien hier bey uns sollen erfunden und ausgesuchet werden, und endlich drittens welche Metalle und Mineralien, hier in diesem Reiche bereits erfunden, und welche noch sollen aufgesucht werden.

[1010] Findet men unzehlich viele verschiedene [Stein-]Arten, welche in Ansehung ihrer unterschiedenen Gestalt, Farbe, Nutzen, Werth und Beschaffenheit auf mancherley Art pflegen unterschieden zu werden, sie können aber am besten eingetheilet werden, in solche, welche entweder in einem gewöhlichen Feuer der Feuers Hitze wiederstehen, und daher feuerbeständige genannt werden, oder auch im Feuer zu Fluss und Glass fliessen, oder auch durch die Feuer-flammen zu Kalck und Pulver gebrannt werden.

grouping was a natural arrangement, following the order ordained by Nature. Bromell said:

> When one places with these the so-called figured stones, petrifications, and diverse stones of animals, he has likely brought the hitherto known kinds of stones into their correct and natural order."[1011]

Although he seems to have regarded his scheme as mirroring the natural order which he thought existed among inorganic bodies, Bromell demonstrated by his emphasis upon describing the properties of minerals that he was less interested in their natural order that he was in the oderly description of their natural characters.

### 9.6.26 Linné

Carl von Linné in his *Systema Naturæ* of 1735 set forth an epitome of a carefully reasoned classification of the plant, animal and mineral kingdoms. He based the mineralogical classification on physical properites of mineral substances.

Posterity has come to regard Linné as the fountainhead of systematic botany, but he also contributed to understanding the animal and mineral kingdoms through his summation and systematization of the works of his predecessors. In the *Systema Naturæ* Linné propounded an all inclusive systematization of natural productions. By means of a careful application of rules of classification to minerals, plants, and animals, he had devised a scheme of classification that reduced Nature's infinte variety to a generalized conceptual scheme.

Extending to inorganic Nature a system of classification designed for plants, Linné organized mineral substances into species, genera, orders, and classes. His classification was presented in the traditional form of a logical–deductive schem, but, he indeicated, it was firmly based upon the study of individual specimens. In his prefatory observations Linné postulated God, Creation, and a generative mechanism, and said: "Individuals thus procreated, lack in their prime and tender age absolutely all knowledge, and are forced to learn everything by means of their external senses." Since the external senses apprehended natural objects, he asked: "why the creator put man, who is thus provided with senses and intellect, on the earth globe, where nothing met his senses byt natural objects, constructed by means of such an admirable and amazing mechanism." He answered his own question by saying: "Surely for no other reason than that observer of the wonderful work migh admire and praise its Maker." Linné said that natural science was necessary to man in order for him to have knowledge of natural objects, from which everything useful originated; but to proceed to knowledge, one must know thing in themselves:

> The first step in wisdom is to knwo the things themselves; this notion consists in having a true idea of the objects; objects are distinguished and known by classifying them methodically and giving them appropiate names. Therefore, classification and name giving will be the foundation of our science.

Thus, he justified his own work of naming and classifying, which he thought to be fundamental to natural science and a major occupation of a naturalist.

Reflecting Becher, the *Systema Naturæ* exhibits the mineral kingdom (*regnum lapideum*) divided into three classes, rocks (petræ), minerals (mineræ), and fossils (fossilia); each class is divided into three orders. The first class, petræ, is characterized as including all simple stones, called gangue (*Bergarter*) by metallurgists, and consists only of similar particles. The second class, *mineræ*, consists of composite stones or ores ...

**[PUT TABLE HERE]**

### 9.6.34 Wallerius

A younger contemporary of Linné, and like him a professor at Uppsala was Johan Gottschalk Wallerius[1012] . Following in the footsteps of Bromell and Linné, Wallerius prepared a systematic treatment of the mineral kingdom based upon a mixture of physical and chemical properties. His book, entitled

[1011] Wann man zu diesen [i.e., the three goups mentioned] die so genannte Figur-Steine, petrificata und allerhand Steine von Thüren leget, so hat man vermuthlich die bishero bekannte Stein-Sorten in ihre rechte und natürlichen Ordnung gebracht.

[1012] Johan Gottschalk Wallerius ...

*Mineralogia, eller Mineral–Riket,*[1013] was described by Nils Zenzén as "a summary of the whole mineralogical knowledge of the time."[1014] Althougth orginally published in Swedish, Wallerius' work was soon translated into several other languages, [1015] thereby promoting Wallerius' classification scheme throughout Europe.

In his forward Wallerius states that his book could serve as a practical guide to determining the characters of minerals and also as a review of the extent and cultivation of the field of mineralogy. [1016] He begins by giving an account in chronological order of the mineralogic accomplishments of several of his Swedish predecessors. He then dispatches all other writers on mineralogy in a sentence: " [1017]

True to his age, Wallerius claimed to have approached mineralogy empirically. He said that he made use of tests in fire and water, correcting here and there his predecessors' work and in places going beyound them. He particularly acknowledged the helpfullness of the work of Daniel Tilas, and set forth his wish that his own work would encourage others to seek out mineralogical knowledge so that in time the area would be even better illuminated. He pointed out that many should engage in the work because "One man's diligence and lifetime is not sufficient to examine all mineral bodies, nor do they exist to found in one place." He cautioned that there was much yet unknown, and that his work was by no means the ultimate study in mineralogy:

> That all kinds of earth, stone, mineral and concretions, should be found enumerated here, no one may well believe, although I applied all pains to bring them together; even less, that all variations and alterations should be found named here. As yet, much in this respect is unknown that the future no doubt is likely to bring

That his scheme of subdivisions was mixed, using both chemical and physical characters to determine subdivisions, was recognized by Wallerius as a distinct shift, but he defended on the basis of greatest usefulness of the classification. He implied that usefulness, rather than logical rigor was the more important determining factor in establishing a mineral classification, for purely descriptive treatment or a purely logical classification do not serve man's needs. An imporatant step was his specific exclusion of descriptive material relating to uses of minerals, which he said could be found in many other books.

As to terminology, he said that he tried to follow a middle course, using clear and simple terms, some derived from mining terms, but in all cases he sought unambigous terms. The usefulness and clarity of his work was considerablly enhanced by the inclusion of Latin equivilents for the Swedish designations of his divisions.

Wallerius clearly and admittedly relied heavily upon the systematic work of his predecessors, particularyly Linné. [see DSB also] Following the pattern set by Linné, Wallerius used four levels of subordination; thus he distributed minerals into species, genera, orders, and classes.

[Put table here!!!]

Wallerius grouped all the productions of the mineral kingdom into four classes (*flocken* ). The first class, *Jordarter*, contains mineral bodies that consist of loose parts that are insoluble in oil and water, but are softened by them. Furthermore, Wallerius held that the *Jordarter* were composed of the same kind of elementary materials taht were the constituents of members of the second class, which he called *Stenarter* (i.e., stones). *Stenarter* are described as densely compacted fine particles that can not be dissolved by oil and water, nor softened by them. When melted and then allowed to solidify, *Stenarter* are said to display a hollow or concave surface. *Malmarter*, the third class, are earths or stones taht contain either salt, sulphur, or metal. They can be dissolved either in water or oil, and they solidify with a convex surface after having been

[1013] Johan Gottschalk Wallerius *J.H.N. Mineralogia, eller Mineral–Riket.* Stockholm: Uplagd på Lars Salvii egen kostnad, 1747.

[1014] Nils Zenzén "Johan Gottschalk Wallerius (1709–1785)," in: *Swedish Men of Science*, edited by Sten Lindroth, p. 103.

[1015] Describe other langauages

[1016] St. Clair, p. 115.

[1017] St. Clair, p. 116.

melted. The final characteristic feature of the class is the heaviness of each member; all are heavier than stone or earth. The fourth class, *Stenhårdnigar*, which includes all fossils, is composed of disrupted and reconsolidated earths, stones, or minerals, and of objects that are produced in an unusual place or generated by a caprice of nature. The parallels between Wallerius' and Linné's treatment of the mineral kingdom are evident at many points, but particularly in Wallerius' Class II, *Stenarter*, is there a close relationship to Linné's Class I, *petræ*. Wallerius characterized the members of the class *Stenarter*, which he postulated were "hard and also its parts hard coherent bodies," in the following way:

1. They can not be scratched easily with fingers or be cut with a knife, and none [can] be scratched with a steel file.
2. They are brittle and fragile, and can neither be hammered nor stretched.
3. As some soften in water, so some can also be dissolved there.
4. Nor in oil can any stone become either harder or softer.

Four orders of stones are distinguished by Wallerius. The order Kalkarter comprises those genera that when burned, fall into dust (i.e., they calcined); also they do not strike fire with steel.[113] The order Glasarter is composed of stones that melt when subjected to fire. They are usually hard, therefore, strike fire with steel. They do not react to acids.[114] The order Eldhärdnigar are those stones that withstand strong heating without changing; they are usually brittle, do not strike fire with steel, and most of them do not effervece with acids. [115] From the descriptions of the group characteristics and a comparision of the species included in each group by Linné and by Wallerius, one can see that Wallerius' order Kalkarter is equivalent to Linné's order calcarii, that the order Glasarter is equivalent to the order vitrescentes, and that Eldhärdningar is equivalent to spyri. Wallerius' fourth order of stones, Hällebärgsarter, for which there is no equivalent order in Linné's class petræ, are common stones. Today one would call them rocks. Wallerius defined them in this way: "Hällebärgsarter are stones, which are composed of the former and described Stenarter, and of which in general every hill and mountain consists, from which, then, those stones lying on the ground loose, that commonly are called either graystones or rubblestones, are torn off through various occasions and spread around."[116]

Wallerius divided each of his four classes into four orders; the resulting sixteen orders contained sixty-seven genera into which four hundered seventy-nine species of minerals were distributed. Linné had recognized fifty genera which contained one hundred sixty species and two hundred forty-two varieties. Linné's descriptions of his classificatory groups were concise, often limited to one main characteristic. Wallerius, on the other hand, attempted to record all of the variety of physical and chemical properties that cound be utilized in the identification of a given mineral. In general, chemical properties were used to distinguish orders, and distinction of species was based upon external characters. The characteristics of genera were a combination of both physical and chemical properties.

Wallerius tabulated the distinctive characteristics of each genera, just as he had carefully listed the characteristics of each class and order. For example, the genus Kalksten contained individuals with the following characters:

At the generic and specific levels, Wallerius included a synoptic synonymy. For Kalksten, he said: "CALCAREUS. Marmor fusaneum. Dioscor. Marmor rude. Linn. Saxum Calcareum. Agric."[118] The first term, "CALCAREUS," indicated the Latin equivalent of the Swedish generic designation (i.e. Kalksten); the other terms were synonyms inferred by Wallerius from the works of various authors, in this case Dioscorides, Linné and Agricola. Similarly, he gave Latin equivalents and previously used designations for the species that he listed. However, in presenting synonyms, cast into his classificatory framework, Wallerius imposed his order upon the work of his predecessors. He imposed an order that was not present in their work.

The concise descriptions of species used

by Wallerius were intended to help in properly identifying, hence categorizing, a specimen. The species Tät Kalksten, for example, was described as "[119]". Superfluous information was included, but it was relagated to appended annotations.

Although Wallerius' work was not an innovation, it was at least a departure from previous works. He incorporated logical rigor such as a exemplified in Linné's work, and he also utilized general chemical principals to guide his divisions into orders.[121] Having had experience in mining matters, Wallerius had an eye for what properties or information would be useful in the identification of minerals. Throughout his work recurs the idea that a classificaiton should serve as an insturment for determination. He thought that his system could be used as a determinstic scheme in order to discriminate and name unknown minerals without description, and with out previous practical knowledge of minerl substances, he hoped a student would be able to identify minerals by using his Mineralogia. Consistent with this goal, Wallerius supplied concise, abstract descriptions and a more precisely–used terminalology. He still was thinking in qualatative terms, however; chemical tests, color, hardness, and other observable propreties were described inexactly and qualitatively.

On the whole, Wallerius' scheme represented a refinement of the work of earlier writers. His work was a welcome addition to the growing literature of systematic mineralogy because of his careful attention to definition and concise description, but there were drawbacks to his system. Wallerius' terminology was often vague and he did not break away from the traditional view that all inorganic terrestial productions – minerals, rocks, fossils – should have a niche in a mineral system. It was reserved to Axel Fredrik Cronstedt, a countryman of Wallerius, to more narrowly circumscribe the mineralogist's purview.

### 9.6.34 Woltersdorff

The system of Johann Lucas Woltersdorff that first appeared in 1748 in Berlin (reprinted 1755) is contained in the book: *Systema minerale, in quo regni mineralis producta omnia systematice per classes, ordines, genera et species proponuntur, oder Mineralsystem.* In many respects this classification is better than that of Linné's, and according to the testimony of the author the emphasis is on the chemical composition.

> The first and preferable basic distinction, for the classification of minerals, must be taken from their internal substance. Because, since the minerals experience niether life, nor growth, and they have also no limbs or sensitive organs with which they can differentiate, they are not organically originated. Moreover, that one has not entirely abandonded this subject on the external form of minerals. It gave vein material from one family, with another that is not entirely similar. In comparision, mankind finds himself with many entirely different types, but all with the same form. One must judge, therefore, the relationship and the difference of minerals, after their mixture, or after the matter, from whence they are collectively built, which produces results upon chemical examination; and hence are determined the classes, orders, and families.[1018]

He did, nevertheless, partially notice the external characters. His division of the earths and stones is essentialially an improvement from that of Pott, which it copies. What he understood about composition, one can derive from the definitions, which are given with his orders and classes. For example, stones originate from the compaction of earthy particles, and are not softened by water; Vitreous stones don't allow themselves to dissolve in acids, but in fire they are easily fused to clear glass; precious stones are usually six sided prisms terminated with a pointed form, transparent, and are never allowed to be sold.

[1018] Woltersdorff in the preface to his mineral system (also quoted in Kobell's *Geschichte der Mineralogie*, p. 63) wrote: Der erste und vornehmste Unterscheidungsgrund, bei Eintheilung der Mineralien, muss von ihrem Bestandwesen hergenommen werden. Denn, da die Mineralien weder leben, noch wachsen, noch empfinden, so find sie auch nicht organisch gebauet, haben auch keine Gliedmasen und sinnlichen Werkzeuge, daran man sie unterscheiden könnte. Hierzu kommt, dass man sich in dieser Sache auf die äussere Gestalt der Mineralien gar nicht zu verlassen hat. Es giebt Bergarten von einem Geschlecht, welche einander gar nicht gleich seyen. Dagegen finden sich welche von ganz verschiedener Gattung, welche einerlei Gestalt haben. Man muss also die Verwandtschaft und den Unterschied der Mineralien, nach ihrer Mischung, oder nach der Materie, woraus die zusammengesezt find, melche sich in chymischer Untersuchung ergibt, beurtheilen; und hieraus sind die Classen, Ordungen, und Geschlechter zu bestimmen.

The purpose of this classification is good, but the execution is on average inferior. Below are the details:

A. Erden [Earths]. I. Thonartige [Argillous]. a. clay. b. soil. II. Kalkartige [Ancaline]. a. chalk. b. marl.

B. Steine [Stones]. I. Glasartige [Vitrescent]. a. precious stones. b. crystal. c. quartz. d. sandstone. e. horn stone. f. fluorite. g. rock. h. pumice. II. Thonartige [Argillous]. a. Smectis. b. asbestos. c. talc. d. mica. e. schist. III. Gypsartige [Gypseous]. a. gypsum. b. alabaster. c. gypseous spar. IV. Kalkartige [Alcalines]. a. limestone. b. marble. c. alcaline spar. d. tuff. e. stalactite. f. margode.

C. Salze [Salts]. I. Säuren [Acids]. a. pure acid. b. vitriol. c. alum. II. Scharfe Salze [Alcalines]. a. fixed. b. volatile. III. Mittelsalze [Intermediate]. a. natrum. b. nitre. c. common salt.

D. Erdharze [Bitumens]. I. Flüszige [Fluid]. a. mountain oil. II. Feste [Solid]. a. amber. b. sulphur. c. mountain pitch.

E. Halbmetalle [Semimetals]. I. Flüszige [Fluid]. a. mercury. II. Feste [Solid]. a. antimony. b. zinc. c. bismuth. d. arsenic.

F. Metalle [Metals]. I. Edle [Noble]. a. gold. b. silver. II. Gemeine [Ignoble]. a. copper. b. iron. c. tin. d. lead.

G. Versteinerungen [Petrifications]. I. Von Thieren mit rothem Bluthe [Of fangineous animals]. a. zoolith. b. ornitholith. c. ichthyolith. II. Von Insekten [Of insects]. a. entomolith. b. gammarolith. c. echinites. d. encrini. e. caput medusae. III. Von Schalenthieren [Of testaceous animals]. a. tubulites. b. cochlites. c. conchites. IV. Von Landgewächsen [Vegetables]. a. stelechites. b. lithoxylum. c. carpolith. d. phytolith. V. Von Meergewächsen [Of marine substances]. a. corallite. b. porite. c. fungite.

Many minerals in Woltersdorff's system are wrongly placed because of insufficient observations by the author. For example he awards to opal the property of crystal form, and classifies it among the precious stones, the petrifications are very oddly grouped, like the division of insects, and shaped stones are frequently confused with fossils. Of the numerous systems from this period, one will find below a survey, from which one can study the continued development. Yet one does not mean that the survey is exhaustive, I have omited various systems.

### 9.6.35 Cronstedt

Axel Frederic Cronstedt[1019] , like Pott and Woltersdorff, believed that mineral classification should rely upon the chemical qualities of the minerals and not on outward characteristics such as form, color, and hardness. Although he had first mentioned this believe in a 1753 letter[1020] to Tilas[1021] , it was the encouragement of his friend von Swab[1022] that persuaded Cronstedt to prepare a manuscript explaining his theories. The first draft reached Rinmann[1023] in November 1756 and by the spring of 1757 the work was completed[1024] . Cronstedt's belief in the project waned, however, for on May 12 of that year he wrote to Tilas that he was not planning to publish his ideas[1025] . Cronstedt's doctor, Jonas Bergius, upon reading the document successfully reversed the decision by persuading Cronstedt to publish anonymously. With the help of his brother, Bengt Bergius, the necessary money was supplied, and thus *Försök til Mineralogie, eller Mineralrikets upställning*[1026] appeared in 1758.

The reluctance of Cronstedt to publish

[1019] Axel Frederic Cronstedt (born: 23 December 1722 at Turinge, Sweden; died: 19 August 1765 at Säter, Sweden) Through the influences of Johan Wallerius and Sven Rinman, he became interested in mining and metallurgy. In 1748 he was made director of East and West Bergslagen, a large mining district in Sweden. With this position came access to excellent laboratories, which enabled him to study mineralogy and chemistry. In 1751 one series of experiments on an ore sample yielded a new metal, which Cronstedt named nickel. Throughout his life he regularly published monographs.

[1020] N. Zenzen, *Svensk Biografiskt Lexikon*, **9**, p. 281.

[1021] Daniel Tilas (born: 23 March 1712 at Gammelbo, örebro Län, Sweden; died: 27 or 28 October 1772 at Stockholm, Sweden) Tilas was appointed assessor at the Swedish mining academy in 1745. Thereafter he was reguarly promoted to positions of authority on account of his many writings praising the mineral wealth of Sweden.

[1022] Anton von Swab (born: 9 August 1703 at Fahlun, Sweden; died: 28 January 1768 at Stockholm, Sweden)

[1023] Sven Rinmann (born: 12 June 1720 at Upsala, Sweden; died: 20 December 1792 at Eskilstuna, Sweden)

[1024] N. Zenzen, *Svensk Biografiskt Lexikon* **9**, p. 283

[1025] N. Zenzen, *Svensk Biografiskt Lexikon* **9**, p. 284

[1026] *Försök til Mineralogie, eller Mineralrikets upställning.* Stockholm, Tryckt uti Wildiska tryckeriet, 1758.

seems surprising, but he recognized the controversy his ideas would generate in mineralogical circles. He atoned for anonymity by making the following statement in the preface:

> I have thought proper to conceal my name, to prevent any constraint on myself or others, and with a view to be at a greater liberty to amend the System, whenever I shall be convinced there is a necessity for so doing, either by my own experience, or by the observations of others: For I flatter myself that this work will not pass unnoticed by men of letters; and, as it is only Essay, it ought, according to an established law amongst authors, to be sheltered from too few centures.[1027]

His identity was not long concealed however, although there was some confusion[1028] . Cronstedt had gained some notoriety from his discovery of nickel in 1751, but it was his *Essay* that would gain him fame among his contemporaries.[1029]

The classification Cronstedt proposed was a large departure from previous practices, because it was based upon the minerals theoretical and practical chemical properties. Earlier researchers had attempted a similar approach[1030] but because chemical theory was still in an infant state these attempts were not totally successful. In his time however, Cronstedt had an important foundation on which to build his system. Analytical chemistry had developed to the point where accurate qualitative analysis could be routinely preformed, usually with a deceptively simple tool, the common blow-pipe for it is in the ability to determine the elements making up a mineral where a successful classification system would lie.

The first important decision Cronstedt made concerned what he would include within the scope of his classification. He began his *Essay* by giving a definition of a mineral.

> The Mineral Kingdom contains all those bodies which have been formed under the surface of our earth, whether at the first creation, or any other time since that period; and which are still daily produced from their original or primary principles, being destitute of seed, life, or any circulation of fluids.[1031]

Cronstedt apologized for the generality of this definition explaining in a footnote that the distinctions between the three natural kingdoms was difficult to accurately define[1032] . In fact, "he operated for the most part from the unstated premise that everyone knew what a mineral was anyhow."[1033] In applying his conditions of *mineralness* (i.e. the state of being a mineral) however, Cronstedt excluded many objects that hitherto had been considered part of any mineral classification.

*Lusi Naturæ* translates to jest of nature, and refers to those mineral objects that resemble manmade items or living beings were not treated as a distinct objects because they existed across all the divisions and therefore were not deserving of a unique group[1034] . Figured stones are similarly treated[1035] . Stones that are found in animals and fishes are excluded[1036] and petrifications are separated from minerals because they

> consist of such principles as ought to be described in their proper places, without regard to their figure; for which reason they cannot be enumerated a second time. The principal reason for collecting them, is to acquire a knowledge of such bodies of the animal and vegetable kingdoms, as are not usually found in their natural state, and in this respect they belong properly to the studies of the Botanists and Zoologists.[1037]

Cronstedt's objective in imposing such limitations was to reduce the number of items his system would have to classify. He was aware how-

[1027] A.F. Cronstedt, *Essay Towards a System of Mineralogy*. London, 1772, p. vii.

[1028] Several people assigned credit for the work to von Swab. Von Engström, who knew both von Swab and Cronstedt during the period when the *Essay* was written states Cronstedt to be the author in his translator's preface. See: Cronstedt, A.F. *Essay Towards a System of Mineralogy*, London: 1772. p. ii.

[1029] St. Clair, p. 133.

[1030] F.A. Cronstedt, *Essay Towards a System of Mineralogy*. London, 1772. pp. viii- ix. "Hiärne and Bromell were, as far as I know, the first who founded any mineral system upon chemical principles."

[1031] F.A. Cronstedt, *Essay*, p. 1.

[1032] F.A. Cronstedt, *Essay*, p. 1 (note).

[1033] St. Clair, p. 137.

[1034] F.A. Cronstedt, *Essay*, p. xviii.

[1035] F.A. Cronstedt, *Essay*, p. xviii.

[1036] F.A. Cronstedt, *Essay*, p. xix.

[1037] F.A. Cronstedt, *Essay*, p. xiv-xv.

ever, the opposition this position would cause, and in a predictive response intended to strike a tolerant balance, Cronstedt said: "If some objects are thrown out from mineral collections on account they do not belong to them, other collections will be augmented; and thus every thing will be brought into due order".[1038]

The classification, abstracted in Table 21, recognized four classes of mineral bodies: earths, inflammables, salts and metals. The earths were defined as "those mineral bodies, not ductile, for the most part not dissoluble in water or oils, and that preserve their constitution in a strong heat," and they were "arranged according to their constituent parts, as far as hitherto discovered, and are divided into nine orders"[1039] . By the word *Earths*, the author was not implying the usual friable materials that had previously been called earths.; rather, he meant all minerals that met his physical and chemical criteria. Thus those items more generally called stones which in previous classifications had been separated were incorporated into Cronstedt's class of Earths.

[ADD TABLE OF SYSTEM HERE?]

By merging the earths and stones together, Cronstedt was inforcing the claim of Pott that the past division was unjustified reling upon chemical analysis to place the species, the earths and stones were shown to "consist of the same principles" and "they are by turns converted from one into the other, insomuch that an earth may in length of time become hard as stone, and vice versa ...,"[1040] thereby justifing their inclusion under the same class.

He was obligated, however, to divide the earths into nine separate kinds, each of which he designated as an order of the class of earths. To distinguish one class from another Cronstedt provided sets of group characters, of which the third order, *The Garnet Kind*, is a representative example of his use of physical and chemical characteristics:

1. It is more fusible, in proportion as it contains less metallic matter, and is more transparent or glassy in its texture; which is quite contrary to the siliceous kind.
2. This is the reason, perhaps, why the garnet, mixed with salt of kelp, may on a piece of charcoal be converted to a glass by the blow-pipe, which cannot be done with the flints.
3. Why the most transparent garnet may, without and addition, be brought to a black opaque flag by the same means.
4. It is never, so far is hitherto known, found pure, or without some mixture of metal; and sepecially iron, which may be extracted by the common methods.
5. The garnet matter, during the cristallisation, has either been formed in small detached quanities, or else has had the power of shooting into crystals, though closely confined in different substances: since garnets are generally found dispersed in other solid stones, and oftentimes in the harder ones, such as quartz and chert.[1041]

From his mention of a blow-pipe as well as chemical reagents throughout the group characteristics, Cronstedt was obviously empahsising a chemical-experimental approach to classing the minerals. At this time however, he could not ignore phyiscal properties completely; therefore, relative hardness, transparency, luster, texture, flexibility, brittleness, and heaviness appear in the diagonistic characters of several orders[1042] .

The second class, *Salts*, were said to be "those mineral bodies ... which can be dissolved in water, and give it a taste; and which have the power, at least when they are mixed with one another, to form new bodies of a solid and angular shape, when the water in which they are dissolved is diminished to a less quanity than is required to keep them in solution; which quanity is called Cristallisation."[1043] To reinforce his position that only naturally occuring salts should be placed in a mineral system, Cronstedt added a note explaining why certain salts known in chemistry are not included: "No other salts ought to be considered and ranked in a mineral system, but those which are found natural in the earth; and for this reason a great number of salts will be

[1038] F.A. Cronstedt, *Essay*, p. xix-xx.

[1039] F.A. Cronstedt, *Essay*, p. 9.

[1040] F.A. Cronstedt, *Essay*, p. xiii.

[1041] Cronstedt, *Essay*, p. 76-77.

[1042] St. Clair, p. 139.

[1043] F.A. Cronstedt, *Essay*, p. 126-27.

in vain looked for here, viz. all such as are either natural or prepared by art in the other two kingdoms of nature, and from substances belonging to them."[1044] Information on these excluded salts had to be found in other books[1045] .

The third class of minerals Cronstedt recognized were the inflammable mineral substances or *Phlogista Mineralia*, which were explained to be "all those subterraneous bodies that are dissoluble in oils, but not in water, which they repel; catch flame in fire; and are electrical."[1046] Included within this division are those substances that could be burned, and were of either a pure or mixed nature. The pure varieties included amber, amber grise, and rock-oil, while those that were mixed contained sulphur, "that ... [is] ... dissolved, or saturated with metals ..."[1047] . Thus pyrite and other metallic sulphides are listed here. Cronstedt recognized that many minerals could be said to be phlogiston in nature, but that this class contains only those bodies in which it is a principle constituent[1048] .

The fourth and final class, *Metals* were characterized as "those mineral bodies which, with respect to their volume, are the heaviest of all hitherto-known bodies; they are not only malleable, but they may also be decompounded, and in a melting heat be brought again to their former state, by the addition of the phlogistion they had lost in their decompostion."[1049] Unlike his previous classes, however, with the metals Cronstedt violates his own rule of division on the basis of chemical properties. In fact the "metals have commonly been considered more with regard to their malleability than fixity in the fire ..."[1050] ; thus true *metals* were considered malleable, while those that were brittle were termed *semi-metals*. He would have preferred a metals behavior in fire to be its diagonostic as to whether it was *perfect*,[1051] or *imperfect*,[1052] but this also did not produce a completely satisfactory division. Cronstedt does not explain why he chose the traditional approach to classifying metals.

Having described the four classes, earths, salts, mineral phlogista, and metals, "Cronstedt had covered all those bodies that he had initially admitted into the mineral kingdom. His system was complete."[1053] He had applied a chemical-experimental approach to the study of minerals, and created a new form of mineral classifation, which was superior to any system previously employed. However, Cronstedt's approach to the problem was not instantly accepted, although the *Essay* enjoyed a wide circulation[1054] .

Their are two reasons that hindered the acceptance of Cronstedt's *Essay*.[1055] First the scheme employed was not as convient to use as others were. He did not cast the minerals into a standard framework of classes, orders and genra's, rather he utilized the chemical information contained in the minerals themselves to organize the overall structure of the classification. This meant that to determine a minerals relative position, tests had to be preformed to first find the chemistry before it could be categorized. Second, the system is by eighteenth century standards very incomplete. By correctly excluding all those materials that did not meet his conception of a mineral, Cronstedt fragmented what was traditionally considered the realm of mineralogy. Thus organics, mineral aggregates, rocks and other types did not appear in the *Essay*'s system, which doubtless lead to much mistrust on the part of readers, who expected to find such

[1044] F.A. Cronstedt, *Essay*, p. 127 (note).

[1045] St. Clair, p. 140.

[1046] F.A. Cronstedt, *Essay*, p. 150.

[1047] F.A. Cronstedt, *Essay*, p. 155.

[1048] F.A. Cronstedt, *Essay*, p. 162.

[1049] F.A. Cronstedt, *Essay*, p. 163-64.

[1050] F.A. Cronstedt, *Essay*, p. 164 (note).

[1051] F.A. Cronstedt, *Essay*, p. 164 (note). "Those [metals] which can not be destroyed by fire alone are called *perfect*, as gold, silver and platina del pinto.

[1052] F.A. Cronstedt, *Essay*, p. 164 (note). "Those metals which in a calcining heat lose their phlogiston, and consequently with that the former coherency of their particles, are called imperfect, as tin, lead, copper, and iron, and all semi-metals."

[1053] St. Clair, p. 150.

[1054] Translations with multiple editions appeared in: German, 1760 & 1770; English, 1770 & 1772 & 1788; French, 1771; Italian, 1775 & 1778; Russian, 1776.

[1055] St. Clair, p. 158.

items. Cronstedt's methods were to radical to be easily accepted by many naturalists who beleived his restrictions on the definition of a mineral to be unwarrented.[1056] In time however, as more chemical observations and discoveries were recorded, the correctness of Cronstedt's notion of a chemically based classification would be revealed.

### 9.6.36 Bergman

Torbern Olaf Bergman *Sciagraphia Regni Mineralis*. Perhaps edited by Johann Jacob Ferber, this is the first edition of Bergman's important foundational work in mineral classification and nomenclature. In the *Sketch of the Mineral Kingdom, digested according to the constituent parts of the substances that compose it*, Bergman shows his support for classifying minerals according to their chemical composition and not on the then common method of external appearance. Bergman's handbook, which is rich in observations about the chemistry of minerals, went further in regard to the subject than had its predecessors because Bergman had developed a portable blow-pipe kit. With this tool, which he took with him out into the field and was thus able to analyze minerals on the spot for their chemical constituents he was able to create a practical method of classification. In contrast to the previous systems of Bromell and Cronstedt chemcial knowledge had developed to a state where it was possible for a chemical system of mineral classification of to be prepared and be of practical use. Bergman recognized four major groups of minerals: salts, earths, metals, and inflammable bodies, and then subclassified each of these groups, exercising care in trying to provide a more consistent nomenclature than the contemporary standards.

In his attempt to reform mineralogical nomenclature, Bergman set up a systematic approach to the mineral kingdom. It closely follows the naming conventions used by Linneaus to successfully name plants and involving two Latin names. This meant the naming of the mineral by the Latin names of the prevalent alkali, earth or metal combined with the name of the acid. For example, copper chloride would be called *cuprum salitum*. Bergman's nomenclature as used in the *Sciagraphia* was an attempt at a general reform of mineralogical as well as chemical names, and it was successful in this respect being adopted by Louis Guyton de Morveau in the same year, and thus helped to standardise chemical nomenclature. Bergman recognized four classes of pure chemical foundation, called salts, earths, metals, and phlogistic materials. These were translated into Latin as sales, terræ, metalla, and phlogistica. Two other classes were added to hold impure substances, petræ were rocks and petrificata were for organic fossil substances. These classes were then subdivided into genera after the method of Linneaus.

The regard for Bergman as a scientist was such that his student and biographer, P.J. Hjelm, records that before the first edition of the *Sciagraphia* was printed, no less than five different translations of it were announced in different places. Not all of these original announcements materialized, although the text was eventually distributed in five diffrent languages including German, Italian, French, English and Portugese [which see next entries]. All this activity seems to indicate a considerable interest in Bergman's system for mineralogy.

In the Preface to his *Sciagraphia* Bergman stated that he had been urged by J.J. Ferber to publish his manuscript outline of mineral classification. This apparently lead Moström to conclude that the work had been "edited by J.J. Ferber." However, Bergman's text contains no evidence that this was the actual case. The Preface reads:

> In answer to the request of my very good friend, Mr. Ferber, I sent him a small outline of mineralogy in which the minerals were arranged according to their con stituent elements. After looking it over, he asked my permission to publish it. At first I thought it would be better not to publish a work so imperfect, especially considering the number of analyses which remained to be made. Mr. Ferber replied that a perfect method was not yet to be expected in so extensive a field, but that having once laid a foundation I might occasionally make such additions and corrections, in new editions of the work, as future

[1056] St. Clair, p. 160-61.

experiments might make necessary. Indeed I was fully aware that the system would be perfected more quickly if submitted to the inspection of other more discerning Chemists, than if its completion depended solely on me. The different remarks of others will correct errors, which by further work I might have corrected, but if science is advanced, it does not matter by whom. So Genera and Species are given, except in the Appendices which, since they did not properly belong in my outline, contain Genera only. The Genera are based on the principle elements, and the Species on the remaining components. Varieties depend upon external appearances, and are therefore omitted here.

### 9.6.37 Kirwan

Richard Kirwan, an Irishman, was an active participant in many of the scientific debates of his day. In particular he is perhaps best remembered as one of the last supporters of the phlogoston theory which he did not abandon until 1791.[1057] In addition, Kirwan was accomplished in several languages enabling him to maintain an ongoing correspondence with many notable scientists on the continent, including Bergman at Uppsala and Guyton de Morveau at Dijon.[1058] Beginning in 1777 Kirwan took up residence in London, where soon "his house became a well-known meeting place for those distinguished by birth, position, or achievement - particularly science."[1059]

Through his interest in chemistry, Kirwan became involved in various aspects of mineralogy. Eventually, this lead to the 1784 appearance of *Elements of Mineralogy*,[1060] often called "the first systematic work on that subject in the English language."[1061] In the preface, in a tone calculated to mildly embarass the British goverment, Kirwan explains the high esteem placed by other countries on the importance of mineralogic and chemical studies. The author then explains the scope of his treatise:

> I have endeavoured to collect in the ensuing treatise all that has been hitherto done in this science, with some few improvements of my own, modelled and digested in the method that seemed to me most useful.[1062]

He then goes on to explain his purpose is not to present the reader with a detailed description of the various external appearances of each mineral "but rather to determine the characters by which fossils are invariably and permanently distinguished from each other in all times and places. In a word, rather to define the *species* than describe the *individual*."[1063]

The structure of classification Kirwan chose for the 1784 edition of his *Elements of Mineralogy* was that of Cronstedt which was "founded almost entirely on chymical characters ... "[1064] At the time this was an excellent choice because as Kirwan writes this method had "been received by all Europe."[1065] However, the theories of Werner at Freiberg were beginning to take hold. Kirwan, himself, traveled to Freiberg to meet Werner and it was through the German professor that in 1792 the Leskean mineral collection was acquired for the Royal Dublin Society. This was an advantageous purchase for the science of mineralogy because it lead Kirwan to publish in 1794 and 1796 a much enlarged second edition of his *Elements of Mineralogy*,[1066] which

[1057] J. Reilly and N. O'Flynn., "Richard Kirwan, Irish Chemist," *ISIS*, **13** p. 298-319.

[1058] For Bergman, see: G. Carlid and J. Nordström (editors) *Tobern Bergman's Foreign Correspondence*. Stockholm: 1965. For letters written to Guyton, see: W.A. Smeaton "Louis Bernard Guyton de Morveau, F.R.S. (1737-1816) and his relations with British Scientists," in: *Notes and Records, Royal Society of London*, 1967, pp. 113-130.

[1059] E.L. Scott, "Richard Kirwan" in: *Dictionary of Scientific Biography*, edited by Gillipsie (1974) **7** 387-390.

[1060] R. Kirwan*Elements of Mineralogy by Richard Kirwan ...* London: Printed for P. Elmsly, 1784. 8vo: pp. [2], xviii, 412, [12]. Henceforth refered to as R. Kirwan(1784).

[1061] *Encyclopedia Britannica*, 11th edition, 1911, p. 834. Also **Ferguson**, John *Bibliotheca Chemica* (1906) **1**, p. 472 writes: "In 1784 [Kirwan] published his book on mineralogy, which had much success as being the first systematic work on the subject in English. Even now it is an interesting landmark in the history of mineralogy, as it shows the minerals that were known, the system of classification and the amount of knowledge of their composition." Since Cronstedt's work appeared in English translations in 1770 and 1772 and Woodward's classification was published still earlier in 1728, it is perhaps best not to call Kirwan's work the first systematic treatment in English.

[1062] R. Kirwan(1784); p. iv.

[1063] R. Kirwan(1784); p. iv-v.

[1064] R. Kirwan(1784); p. vi.

[1065] R. Kirwan(1784); p. vi.

[1066] R. Kirwan*Elements of Mineralogy by Richard Kirwan ... Second edition, with considerable improvements and additions.* London: Printed by J. Nicols, 1794-96. 2 volumes. 8vo: (I)

was now based primarliy on the mineralogical theories of Werner.[1067]

Kirwan explains in the preface to his second edition that mineralogy before 1780 was not a science as much as it was an art because it lacked a precise definition of its objects.[1068] Refering back to this time, he states this often lead to "the *same* substance, from some slight variation of appearance, ... often [being] denoted by different names, and *different* substances by the same name."[1069] So persausive were the theories emminating from Freiberg, however, that Kirwan claims "descriptive language was at last reduced to as much precision as it was capable of receiving"[1070]

> All the mineralogical collections, therefore, formed before that year, or ever since, if arranged on other principals, are necessarily in many respects defective and erroneous.[1071]

It is exactly because the Leskean mineral collection was arranged on Wernerian principals[1072] that Kirwan was able to update his "Elements of Mineralogy." In fact, the author follows the arrangement of the collection very closely when he divides mineralogy into Earths, Salts, Inflammables and Metals.

[ADD TABLE OF SYSTEM?]

### 9.6.45 Romé de L'Isle

J.B.L. Romé de L'Isle's *Cristallographie* ranks as one of the great contributions to the science of crystals. In it Romé de l'Isle attempted to make a comprehensive classification of crystals. By the time he wrote this volume, he was extremely familiar with the subject, and this work greatly supassed all previous works in scope and detail. To apply his classification, he adopted a morphological approach in which he attempted to relate the diverse forms of crystals of the same substance. As a general morphological concept he introduced the idea of the "primitive form." All crystals of the same inorganic substance, no matter how different in appearance had a fundemental and common geometrical form—the primative form—to which their actual crystal shapes related. The justification for this idea was derived from the previous work of Carl Linneaus who had tried to expain the genesis of minerals by means of an analogy with the procreation of living creatures, and classified cystals by the similarities of their crystallized forms.

In this first edition of the *Cristallographie*, Romé de l'Isle identifies 110 crystal forms by which minerals crystallize. Grouped under each of these shapes are described the minerals that exhibit similar habit, including the approximate angles between crystal faces. These forms were all derived form a common saline ingrediaent in every mineral that worked at a molecular level. Although he believes that these primitive forms existed, it is never made clear how they should be defined for any group of crystals. Romé was able to greatly expand upon this idea in the second edition [which see below].

An annotated bibliography compiled by Romé is listed on pages xvii-xxviii.

**1783 Edition**

Contains the first general announcement of the fundemental law of quantitative crystallography. This is a revised and greatly expanded edition of *Essai de Cristallographie* (Paris, 1772), and although the title page calls this publication a second edition, it has been so greatly enlarged, it could rightly be considered as a separate work. By the time of its publication, Romé had made crucial advances towards a quantitative crystallography. This had been made possible by the recent invention of the contact goniometer by his student, Arnould Carangeot [see note below]. This simple device used for measuring crystalline angular dimensions, led him to generally enunciate for the first time, the fundemental quantitative law of

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pp. xxxi, 510; (II) pp. xvi, 529, [2]. Henceforth referred to as R. Kirwan(1794).

[1067] R. Kirwan(1794); pp. xv-xvi.

[1068] R. Kirwan(1794); p. xi.

[1069] R. Kirwan(1794); p. xi.

[1070] R. Kirwan(1794); p. xii.

[1071] R. Kirwan(1794); p. xii.

[1072] R. Kirwan(1794); p. xii, writes "Of the many excellent disciples formed by Mr. Werner, Leske, the framer of the present collection, was one of the earliest and most emminent ... Upon the decease of Mr. Leske, it was revised and corrected, and enlarged by Mr. Karsten, also a disciple of Mr. Werner's, and, next to him, perhaps the most acute and judious mineralogist now existing."

crystallography—the law of constant interfacial angles.

Previously, Henckel, Bartholin and Steno had observed this constant in pyrite, calcite and quartz, respectively; however, Romé was the first to state it as a general trueism of the physical world. It meant that regardless of the dissimilar appearance of crystals, specimens of the same species would always show identical angle measurements between common crystal faces. In addition, this discovery provided mineralogy with the first exact measurement that could be published without interpretation, and thus be disseminated to other researchers. To this purpose, this edition increases to over 450 the number of possible crystal forms, and providing for each accurate angle measurements between different crystal surfaces made with the goniometer. Armed with his law, he was able to somewhat elaborate on his definition of the primitive form and how it related to the external crystal, but Romé never made the theoretical leap that allowed Haüy to spin an elegant theory from essentially the same information. None the less, Romé captured information from his crystallographical laws and together with his broadened concept of the relationship between crystal form and chemical composition, he made the *Cristallographie* into the finest mineralogical treatise written to the time.

Volume 1, part 1: Salts, acids, alkalines, bases and combinations.; Volume 1, part 2: Crystallization of stones. i.e. gypsum, selenite, calcite. Volume 2: Quartz, tourmaline, feldspar, gems, etc. an appendix deals with rocks and other aggregates. Volume 3: Metals = Zinc, iron, cobalt, lead, copper, gold, silver. An alphabetical table of contents, bibliography.

### 9.6.80 Werner

Werner, who died in 1817, was succeeded as Professor of Mineralogy at Freiberg by Fred. Mohs, who in 1822-24 published in two volumes his " Grundriss der Mineralogie," which was afterwards translated into English by W. Haidinger, and published in Edinburgh in 1825. Before the first appearance of his work, however, Mohs had been in Edinburgh, and had aided Jameson in the preparation of a third edition of the latter's " System of Mineralogy," published in 1820. In the preface to this work, which develops the ideas of Mohs, it is declared that the system there adopted, and called the Natural History method, is in accordance with the views of Werner, and that it is " founded on what are popularly called external characters, and is totally independent of any aid from chemistry." This was, moreover, in the opinion of Jameson, the only method "by which minerals could be scientifically arranged and rightly determined." Physical characters independent of chemical composition constituted, in the language of Mohg, the " characteristic" of mineral species, and served as the basis of his classification. This system of Mohs, as set forth by Jameson and by himself, at once found favor with naturalists, and was adopted by Breithaupt, Werner's successor at Freiberg, of whose " Handbuch der Mineralogie " three volumes were published in 1836,1841, and 1846 ; the fourth and last volume never having ap-peared. A brief synopsis of twenty-two pages, printed by that author in 1855, supplies the characters of the orders which would have been included in the fourth volume, and thus enables us to complete the outline of the system as set forth by Breithaupt. Albin Weisbach, who has succeeded him at Freiberg, published in 1875, and in a later edition in 1884, his "Synopsis Mineralogie a," a farther exposition of the Natural History system of Mohs. In place of the trivial names hitherto adopted in mineralogy, and still generally in use, Mohs proposed an ingenious but somewhat cum-brous German nomenclature, descriptive in its nature, which was translated by Haidinger into English, and was adopted by Jameson. Breithaupt, on the other hand, essayed a Latin binomial nomenclature for genera and species.

**[SEE ADAMS 1938 p. 204 for 1817 Synopsis]**

## 9.7 The Ninteenth Century[1073]

[1073] John G. Burke., "Mineral classification in the early nineteenth century" (pp. 62-77), in: Schneer, J.C., ed., *Toward a history of geology*. Cambridge, Mass., and London, MIT Press, 1969. • B. Voland., "Über die Entwicklung der Mineralsystematik in der ersten Hälfte des

Systematics, whose beginnings extended back to antiquity, represent a substantial portion of the efforts to develop mineralogy into a science. By the nineteenth century advances in chemistry, crystallography, physics, and other subjects had progressed far enough that the older basis of classification could be tossed out and new approaches applied. Systematic organization still encompassed a great deal of the mineralogists' efforts, but by the mid-point of the century a solid and practical foundation for mineral classification was developed.

### 9.7.1 Haüy

In 1801, Haüy's *Traité de Minéralogie* appeared. It is arguably the most influential work written in the entire development of mineralogy and crystallography. It far superseded any previous attempt to create a mineralogical classification. It is a work of comprehensive insight, and much of it, written in literary fluency, repays the casual curiosity of mineralogists and historians of science. Haüy's magnum opus containing his theory of crystal structure and his system of mineral classification. Haüy's law of decrement states led his successors directly to the law of rational indices, one of the fundamental laws of modern crystallography. This work was immediately recognized as the most important offered by France to the science of mineralogy, one that placed the country at the forefront of the European nations in this science. In it the author makes crystallography the basis of his determination of mineral species, relegating the data derived from chemical analysis to second rank. The mathematical precision with which the crystallographic facts could be presented provided an absolutely exact basis for mineralogy which it had lacked before that time, as the correctness of the crystallographic determinations could always be proved by rigid geometrical tests.

In his mineral classification, Haüy believed that chemistry played a secondary rôle to crystallography in determining species groups. The work also contains Haüy's discovery of piezo-electricity.

The work opens with a Preliminary Discourse that assumes the character of a literary dissertation, generally philosophic, frequently eloquent, and always dignified and learned. Haüy first draws comparisons between the study of minerals and the obvious charms of zoology and botany, with their living subjects to study. He then explains the mysteries of the science. The polyhedral shape of crystals for example can bring mathematical precision to the science. Haüy notes the easy separation of natural substances into stones, salts, bitumens, and metals, the quick recognition of crystals, the artificial and purely empirical classification of minerals, by their external characters, combined with a few simple reactions, as the effervescing of carbonates, the later systems of Cronstedt, Bergman, Born, Kirwan, etc., when analysis usurped the place of mere inspection. He emphasizes the importance of distinguishing varieties, as in calcite, a conviction he incorporated into his description of the minerals. He also illustrates the value of analysis in alluding to the mineral smithsonite that was first regarded as a zeolite, later as heavy spar, and then shown conclusively by chemical analysis to be a salt of zinc.

Haüy's system comprised four classes: (1) acidiferous substances; (2) earthy substances; (3) non-metallic combustible substances; and (4) metallic substances. The orders and genera of the first class contained minerals in which the alkali and alkaline earth metals and members of the magnesium and aluminum family were combined with acids. Species of the first genus of the first order were calcite, apatite, fluorite, and gypsum; those of the second genus of the first order were barite and witherite ; those of the third, celestite and strontianite ; and those of the fourth, epsomite and boracite. Saltpeter was a unique species of the first genus of the second order; the species of the second genus were halite, borax, and sodium carbonate ; sal ammoniac was a unique species of the third genus. The third order consisted of a unique genus containing two species, alum and cryolite.

But Haüy's work in crystallography was

19. Jahrhunderts durch die Schüler Werners," *Freiberger Forschungshefte*, **C-223** (1967), p. 179-90. [Development of systematic mineralogy through the students of Werner during the first half of the 19th century.]

a major contribution to the development of mineralogy. His meticulous attention to the forms of crystals allowed him to unite in the same species minerals that had previously been listed as separate species, such as beryl and emerald, and to distinguish a number of minerals previously lumped together, such as the "zeolites." Above all, Haüy directed attention to the internal structure of crystals and demonstrated that regularity of the external configuration was merely a manifestation of internal order. Haüy's laws of decrement led directly to the development of modern systems of crystal classification and to the idea of the space lattice.

### 9.7.3 Berzelius

First man the one such on purely chemical basis to set up tried, was J. J. BERZELIUS (1779-1848), which expressed also first the sentence that the mineralogy was to be regarded as a part of chemistry; its "Mineralsystem " (first German 1815 appeared) suffers however from many lack, which also the changes of the same remedied by N. G. NORDENSKIOELD (1792-1866) only to smaller parts.

Already in 1815 Berzelius had proposed a purely chemical system of mineralogical classification, based upon his electro-chemical hypothesis, in which all compounds were regarded as made up of an electro-positive or basic, and an electro-negative or acidic portion. He brought together in a single family all compounds containing the same electro-positive portion, and arranged the families among themselves according to the degree of the electro-positivity of the metal; each family being divided into orders, arranged according to the degree of the electro-negativity of the acidic portion. The arbitrary nature of this system being made manifest by the discovery of isomorphism by Mitscherlich, Berzelius in 1824 proposed a new arrangement, dependent on the electro-negative or acidic portion of the compound, which in its essential features has since been adopted by chemical mineralogists, and notably by Rammelsberg, who in 1841 published his " Chemical Mineralogy." Such a classification, avowedly taken from Rammelsberg, was given as an alternative scheme by Dana in his second edition, while still retaining the natural history classification. In his third edition, in 1850, Dana put forth a new chemical classification, "in which the Berzelian method was coupled with crystallography." Since that time an essentially chemical system has been followed by him in his later editions of 1854 and 1868, and in the "Text-Book of Mineralogy" of EdwardS. Dana in 1882. Such a system somewhat modified was adopted by Naumann, and is set forth in the twelfth edition of his " Elemente der Mineralogie," revised and edited by F. Zirkel in 1885. The chemico-crystallographic conception of mineral classification finds its simplest expression in the " Tabellarische Uebersicht der Mineralien" of Groth (2d edition, 1882), where the trivial name, together with the crystalline form and the chemical formula of the species are given, without any reference to hardness, specific gravity, or any other physical characters whatever.

### 9.7.3 Mohs

For the better understanding of the student it will be well to give an analysis of the Natural History system of Mohs, with a notice of some of the changes introduced by his followers. Mohs, and, after him, Shepard included all native minerals in three classes : I. Saline bodies, sapid if solid; together with all liquids and gases. II. All insoluble minerals having a specific gravity above 1.8 ; water being unity. III. Resins and coals. 12. The second class which, as will be seen, included all insoluble mineral species, save the resins and coals, was divided by Mohs into fifteen orders, as follows : 1, Haloide ; 2, Baryte ; 3, Kerate ; 4, Terene ; 5, Malachite ; 6, Mica ; 1, Steatite ; 8, Spar ; 9, Gem ; 10, Ore; 11, Metal; 12, Pyrite; 13, Glance; 14, Blende; 15, Sulphur.

The order Spar as defined by Mohs included not only all zeolites, scapolites and feldspars, with sodalite, nepheline and leucite, but petalite, spodumene and cyanite, as well as pyroxene, amphibole, wollastonite and epidote, these last four being made species of the genus Augite-Spar. Other genera were Schiller Spar;

Disthene-Spar, including cyanite ; Triphane-Spar, com prising spodumene and prehnite ; Petaline-Spar for petalite ; Azvre-Spar for lapis-lazuli and lazulite ; Held-Spar, embracing adularia, albite, anorthite, labradorite and scapolite. In the ge nus Kouphone-Spar were grouped not only leucite and sodalite, but the characteristic zeolites-mesotype, laumontite, harmotome, analcite, chabazite, stilbite and heulandite. With these was also placed apophyllite, while datolite was assigned to a new genus Dystome-Spar.

### 9.7.4 Nordenskiöld

Nils Gustaf von Nordenskiöld *Försök till framställning af kemiska mineral–systemet* 1827.

In this *Proposal for a Chemical System of Mineralogy*, Nordenskiöld' unites the chemical theories of Berzelius with his own analytical work with which he was then engaged.

### 9.7.5 Breithaupt

Breithaupt, who in his *Handbuch* (1823) introduced many changes into the system, made four classes :

I. SALES (Salts)
II. LAPIDE (Stones)
III. MINERS (Ores)
IV. ISTFLAMMABILIA (Combustibles)

He thus divided in two the second class of Mohs, in which he is followed by Weisbach. In the above arrangement, as in that of Mohs, soluble carbonates, sulphates, borates, chlorids, etc., are placed in the first class, far away from the insoluble ones, and thus a ready solubility in water at ordinary temperatures is made a class distinction. Passing to the second class, Breithaupt recognized nine orders, as follows : 1, Phi/llites, including gypsum, pharmacolite, cobalt-bloom, uranite, chalcophyllite, etc. ; 2, Chal-cites; some harder and denser green-colored phosphates, arsenates, carbonates, etc., including malachite, azurite, olivenite, and, also, the silicates dioptase and chrome-garnet, or ouwarovite ; 3, Spathi (spars), including besides all the carbon-spars, or carbon-ates of lime, magnesia, baryta, strontia, iron, manganese, zinc, lead, etc.; sparry sulphates, as anhydrite, celestite, barytine ; cryo-lite, fluorite ; sparry phosphates, as apatite, arsenates, chromates, tungstates, molybdates, and even certain silicates, such as eulytite and datolite ; 4, Cerates, comprising the chlorids and iodids of silver and mercury ; 5, Porodini, amorphous, colloidal, or porodic species, to be again mentioned below ; 6, Micm (micas), including besides true micas, chlorites and talc, certain non-silicated species, micaceous in structure, such as brucite, hydrargillite and pyrosma-lite ; 1, Zeolithi (zeolites), comprising besides the true zeolites, the silicates apophyllite and dysclasite, and the phosphate wavellite ; 8, Gramtnites, embracing, besides the feldspars, scapolites, petalite, leucite, sodalite and related silicates, the great family of am-phiboles and pyroxenes, with chondrodite; silicates like wollastonite, troostite and willemite, calamine, pectolite, epidote, spodumene, prehnite, cyanite and fibrolite, and finally the phosphates, ambly-gonite and lazulite ; 9, Sclerites, including garnet, helvine, idocrase, beryl, phenacite, euclase, tourmaline, axinite, dichroite, chryso-lite, topaz, zircon, staurolite, andalusite, sphene, quartz, periclase, spinel, corundum, chrysoberyl, boracite and diamond ; besides opal, tachylyte, obsidian, pitchstone and similar amorphous or porodic species, which he included in one genus, Amorphites.

In class three of Breithaupt, MINER JE (ores) are five orders : 1, Aerm (oxydized ores), including the native oxyds of iron and manganese, both anhydrous and hydrous, with chromite, ilmenite, and various titanates, columbates, tantalates, tungstates and molyb-dates, also cuprite, zincite, pitchblende, cassiterite, rutile, and related species, with such silicates as lievrite, cerite, orthite, allanite and thorite ; 2, Pyrites ; the harder compounds of the metals, iron, cobalt, nickel, etc., with sulphur, arsenic and antimony, of which pyrite, millerite, smaltite, arsenopyrite and niccolite are types, and including also iridosmium ; 3, Metalli ; native metals and alloys ; 4, Lamprites or Glances ; the compounds of silver, lead, copper, mercury and molybdenum, with sulphur, selenium, tellurium, arsenic, bismuth and antimony ; Minia or Blendes, including sul-

phids of zinc, cadmium, manganese, mercury and arsenic, and also sulpharsenides and sulphantimonides like the red silver ores. Class four, Irvflammabilia, or combustibles, included four orders: 1, Sulphur ; 2, Jlesince; 3, JBitumina ; 4, Carbones.

### 9.7.7 Beudant

A highly regarded textbook, considered at the time of its publication to be the best authority in French mineralogy, and used in centers of higher learning throughout France. At its appearance it was the best treatment of Berzelius chemical classification of minerals. In the first portion, Beudant provides a comprehensive introduction to mineralogical science, including definitions, crystallography, physical and chemical properties, nomenclature, and an overview of his system of classification. The bulk of the volume is a descriptive mineralogy arranged according to this classification. Tables at the end provide an analysis of the specific wieghts of simple bodies and acids and a description of a new form of goniomenter.

Earlier mineralogical investigations, particularly experiments with carbonates and other salts, showed Beudant a relationship between chemistry and crystal form that he expressed as Beudant's law. In essence, he discovered that when two compounds were dissolved within the same solution and precipitated together, the properties of the resulting crystal were determined by both substances. For example, the interfacial angle would have a value intermediate between the angles of the original compounds and proportional to the amount of the compound within the crystal. Within the *Traité* Beudant expands upon the relationship between chemistry and crystal form by developing a system of classification based on a mineral's chemical makeup.

The system Beudant adopts was a device of his own research in which he follows Berzelius and utilizes the electronegative component of the mineral to arrange it within the system. He begins by writing how unscientific the current state of mineralogy is, and his wish to remove everything arbitrary in classifying minerals. After surveying the various properties of minerals, he defines mineralogy as the "la réunion des minéraux de mème composition." To present the idea to the reader, he ranks the known elements into three groups: *Gazolyten* (make volatile compounds), *Leucolyten* (produce uncolored oxide compounds) and *Chrocolyten* (combine into colored compounds). Under each of these groups are now creates subgroups based upon the minerals' electronegative element, taking into account isomorphic substances. Thus, mineral groups such as carbonates are found together in the system. Beudant provides supporting evidence for the correctness of the system by showing the similarity in physical properties of minerals within with in these groups, thus anticipating Gmelin who a short time later showed the influence of the electronegative element on crystal form and physical properties. Beudant then continues to subdivide the system into various series by his own analogies.

Beudant strongly believed chemistry and the conditions during a minerals formation determined its crystallography. He writes that the diverse crystal forms of the same substance was not mere chance, but controlled by the chemical conditions of the environment when the crystal formed. He points out that the same crystal forms are seen at different localities where analogous geological conditions are found. Conversely, when neighboring minerals and rocks were different, a different crystal form would also occur.

In the use of chemical formulae, Beudant accepted Berzelius idea of using symbols to describe elements within formulae of the mineral species, however, in the *Traité* he modified the symbols to be based upon the French names of the elements rather than the Latin proposed by Berzelius. Thus he wrote E (*Étain*), M (*Mercure*), O (*Or*), Ox (*Oxigène*), etc. Berzelius took exception to this display of French pride, and pointed out that if each nation were to do the same modification, all advantage to the precise communication among chemists would be lost. In the second edition of the *Traité*, Beudant changed his symbols so as to conform with the Latinized names of Berzelius.

### 9.7.9 Shepard

Charles Upham Shepard, in 1835, in the first edition of his *System of Mineralogy*, adopted both the classification of Mohs and his nomenclature as translated by Haidinger. In the second and third editions of this same work, in 1844 and 1852-1857, while retaining with slight modifications the classes and orders of Mohs, Shepard abandoned his nomenclature, and reverted to the trivial names previously and still in general use. James D. Dana, in the first and second editions of his *System of Mineralogy*, in 1837 and 1844, adopted the Natural History method of Mohs.[1074] He moreover devised a Latin terminology for the orders, as well as a Latin binomial nomenclature of his own for genera and species, which has, however, never found favor, and was dropped by himself in his third edition, in 1850, when he abandoned also the Natural History method of Mohs.

### 9.7.11 Dufrénoy

This is an important mineralogical and crystallographic work in the history of those sciences. Haüy, gone for over twenty years when these volumes appeared, no longer dominated the French school. Chemistry and crystallography had made major discoveries, making it possible to advance to a more successful theoretical stage in mineral classification. New original research was being carried on, as is evident by the amount of information contained in these volumes. Here the author describes the effects of high temperature on minerals and crystals and gives theories about the structure of crystals, together with the standard information about the physical characters of minerals, chemical properties, crystal systems and systematic mineralogy, in which the author follows a natural method of classification.

Advances in the chemical composition of mineral species now allowed Dufrénoy to employ chemistry as a true means of classification. He uses this classification because he believes it brings together all observations made in the science under a single, unified explanation. However, he believed that using the bases to classify metals, gave birth to true natural groups in which there was one common element. For example, all those of lead, all those of copper, and all those of iron. On the other hand, silicates were their own distinct group because hardness, luster and other properties were similar. Dufrénoy believed then, that classification by acids should be confined to the silicates.

In the first volume of the text are seven folding engraved plates, four of which are detailed renderings of mineralogical instruments: goniometers (Haüy, Wollaston, Mitscherlich, Adelmann and Babinet), Soleil refractometer and a Soleil polariscope. The atlas volume contains over 200 engraved plates showing more than 1,200 crystal diagrams with references to Naumann's crystal notation.

### 9.7.11 Pansner

Johann Heinrich Lorenz von Pansner [1777-1851] in a pamphlet published in St Petersburg in 1813 titled, *Resultate der Untersuchungen über die Härte und specifische Schwere der Mineralien*, seems to have been the first to adopt the plan of testing the hardness of minerals, not by scratching them upon each other but by means of a series of diamond and metal points. Later he wrote a memoir in both Russian and German describing a classification system based on the hardness of minerals.[1075] He classifed

[1074] In 1844 he wrote: " We would not say that the system of Mohs, adopted in this trea-tise as the natural system, is perfect; yet, whether we consider it chemically or mineral-ogically, it will be found to approach more nearly to such a system than any other that has been proposed." Again, he adds : " The striking beauties of the system [of Mohs] will forcibly impress the minds of those who give it the attention it merits." (J. D. Dana, " Min-eralogy," 2d ed., pp. 130,134.) In 1850, however, his views had undergone a complete change, as announced in the Preface to his third ed., referring to which in 1854 he writes : " The system of Mohs, valuable in its day, had subserved its end, and that, in throwing off its shackles for the more consistent principles flowing from recent views on chemistry, the many difficulties in the way of perfecting a new classification led the author to an arrange-ment which should ' serve the convenience of the student, without pretending to strict science.'" He adds, referring to the first and second editions: " The arrangement of Mohs, followed in the main in those editions, cannot stand the test of the developments of science. Even on the assumed ground of being a natural system, it is in many parts singularly artificial." (" Mineralogy," 4th ed., pp. 6, 255.)

[1075] L. Pansner., "Systematische Anordnung der Miner-

minerals as follows:

a. Adamanti-Charattomena (scratchable by a diamond, but not by a steel graver)
b. CJudybi-CJiarattomena (by a steel but not by a copper graver)
c. Chalco-Charattomena (by a copper but not by a lead graver)
d. Molybdo-Cliarattoniena (by a lead graver)
e. AcJtarattoinena (those whose hardness cannot be tested by scratching)

These classes formed by relative hardness are again subdivided according as the specific gravity of the mineral is less than 1, less than 2 etc., into (0) Natantia, (1) Hydrobarea, (2) Dirhydrobarea, (3) Tri-hydrobarea etc., etc. Pp. 183-202 (erroneously paged 173) are occupied with a table of several hundred minerals thus classified, with the specific gravities to four places of decimals. The remainder of the memoir does not relate to hardness but to a classification of inorganic substances by other physical characteristics.[1076]

### 9.7.41 Haidinger

*Handbuch der Bestimmenden Mineralogie* (1845). Organized upon the Mohs system of classification but containing Haidinger's own ideas.

### 9.7.44 Hausmann

Johann Friedrich Ludwig Hausmann *Entwurf eines Systems der unorganisirten Naturkörper* (1809). The primary force behind the existance of this work were discussions between Gustav Magnus Schwartz [q.v.] and Hausmann concerning an appropriate system by which mineral substances could be organized. After Schwartz's death, Hausmann endeavored to fullfill a promise made to his collaborator and published this discourse, which outlines their system.

*Handbuch der Mineralogie* (1813) A thorough compendium classifying every known mineral species. Following the introduction is an overview of the classificaiton system. The system Hausmann follows in this enterprise, was originally presented in his *Entwurf eines Systems der unorganisirten Naturkörper* (Cassel, 1809) [see above entry]. Only slight modifications have been made to the system from the earlier work. After this overview the more detailed descriptive mineralogy arranged according to the outline is presented. It is divided into the classes of combustibles, incombustibles, earths, oxides, acids and salts. Throughout the volumes Hausmann has applied careful and judicial judgement in expressing his own views and the mention of new discoveries and theories. Volume three concludes with two indexes. Each lists the described mineral spieces, one referencing names in German, while the other lists names in French.

*Handbuch der Mineralogie* (1828-47) . Part one of this work, comprising the first volume, is a comprehensive, well thought out introduction to mineralogical science. In the forward, Hausmann writes that this new edition of his *Handbuch* is made necessary by the many changes in the science of mineralogy, particularly with regard to chemistry and crystallography. All parts of the science had undergone transformation and there had been new discoveries. After presenting a generalization of these events, Hausmann explains that these changes are digested into this introduction. In this first part, the basic concepts of the science are covered. Included is material on terminology, theoretical principles, nomenclature, and systematic classification. The second portion of the work was published in two volumes and consists of the descriptive mineralogy. As in the previous edition, all know mineral species are described in the classification devised by Hausmann.

### 9.7.45 Rose

This only eliminated due to the mineral-chemical opinions of its pupil Gusav ROSE in the writing, completely changed since the discoveries MITSCHERLICHS, *Das krystallo chemical mineral system*, Leipzig 1852. In the introduction to this Rose gives works a masterful representation of those lack and the dif-

alien in Klassen nach ihrer Härte, und Ordnungen nach ihrer specifischen Schwere," *Mémoires de la Société Impériale des Naturalistes* (Moscow), **5** (1817), p. 179-243.

[1076] Todhunter, *History of the Theory of Elasticity and of the Strength of Materials*, 1886-93, **2**, pt. 1, p. ??-??.

ficulties for the list one "Systems", which result in particular from the fact that many minerals are isomorphic mixtures of different connections and which he strove by the summary of isomorphic rows to meet; above all its work supplied first the criteria for the understanding of the verwandtschaftsverhaeltnisse of the most important groups of minerals, particularly the silicates. By essentially still today valid views it determined the incompleteness of everyone "Mineralsystems " and its dependence on the respective conditions of chemistry. Its *Krystallochemisches mineral system*, which begins with the elements and attaches to these the sulfur connections, is now the basis become for the arrangement of the minerals in all newer lehr and manuals, as well as in tabular compositions the same. The changes, which were made into individual these works, are partly due to the progress of mineral chemistry, partly by considerations of practical kind, thus not of general importance for the development of the science and can find therefore in their history just as little place, like the discovery of new minerals.

### 9.7.50 Dana

The system of mineral classification that was eventually adopted by most mineralogists was first proposed by James Dwight Dana (1813-1895) in the 1850 third edition of his *System of Mineralogy*. Dana's major divisions of minerals were based on chemistry; elements, halides, sulfides, silicates, carbonates, and other chemical groupings were used. Within each of these categories further subdivisions were largely based on structure; Dana grouped together all carbonates with the calcite structure, for example. Physical properties, as in Werner's system, were reviewed in great detail and provided the basis for mineral identification. The classification and description of minerals continued to occupy much of the effort of mineralogists in the second half of the nineteenth century as the systems of Dana and Gustav Rose (1798-1873), in particular, were expanded and refined. Alternative classifications were advanced in the late nineteenth and twentieth centuries, primarily on the basis of economic or structural considerations, but the crystal chemical method has remained the most widely employed basis for mineral classification.

### 9.7.61 Kobell

Franz Wolfgang Ritter von Kobell *Grundzüge der Mineralogie* (1838).

Kobell's enlargement of Berzelius' system which classified minerals according to their chemical composition. In this important work, Kobell expands the chemical analyses of minerals in new directions. It is based upon the newest discoveries in mineralogy, especially the work carried on by Thomas Thomson in *Outlines of Mineralogy, Geology and Mineral Analysis* (2 vols., London, 1836), as well as Kobell's own researches. He utilizes the theories of Naumann in crystallization. He ignores species about which their chemical composition is not known.

### 9.7.75 Hunt

*Systematic Mineralogy Based upon a Natural Classification.* A unique book in many respects and of considerable interest for the "natural history" method the author adopts for mineralogical classification. It is remarkable for material that is seldom advanced in other texts and overall, this book should be viewed as a highly interesting and instructive series of essays that give Hunt's ideas on various aspects of mineralogy. An excellent review of other mineralogical systems of classification is included as discussions on chemistry, physical properties, formation of minerals, theory of solution, crystallization, chemistry of species, nomenclature, etc. The work concludes with a good index.

### 9.7.77 Weisbach

Weisbach published in 1875, in his *Synopsis Mineralogica*, a modification of the system of Mohs. Class I. of Weisbach, HYDROLYTE or Salts, includes compounds soluble in water, while Class II., LITHE or Stones, is divided into three orders : 1, Kuplioxyde / 2, Pyritite (silicate), including four families : a, Sklerite ; b, Zeolite ; c, Phyllite ; d, Amorphite ; and 3, Apyritite (non-silicate). Class III., METALLITE or Ores, is divided into four orders; 1, Halometallite ; 2, Metalloxyde; 3,Metalle ; 4, Thiometalle, the last including

three families : a, Pyrite ; b, Galenite (Glances) Cinnabarite (Blendes). Class IV., KAUSTE or Combustibles, includes five orders : 1, Ametalle (Sulphur) ; 2, Anthracite (Coals); 3, Asphaltite (Pitches); 4, Rhetinite (Resins); 5, Paraffine (Waxes).

The oxyds are divided between the Kuphoxyde and the Metalloxyde, or those of the lighter and the heavier metals. In Halometallite are found the silicates of yttrium, zirconium, thorium, cerium, zinc, copper, iron, and manganese, together with columbates, tantalates, tungstates, chromates, as well as arsenates, phosphates, sulphates, carbonates, fluorids, and chlorids of the heavy metals ; the corresponding compounds of the lighter metals coming under the order Apyritite of Class II. In a second edition of the Synopsis, in 1884, the Halometallite are made an order in a new class called Metallolithe or Metalstones ; while the order Asphaltite is divided by separating it from the order Elabite (Petroleums). His three families of Halometallite, namely, Pyrite, Galenite, and Cinnabarite, correspond to the three orders of Pyrites, Lamprites, and Minia of Breithaupt.

**[SEE BEEKMAN, P. 183.]**

### 9.7.81 Knop

By the late nineteenth century, chemistry and mineralogy were considered two distinct studies, although earlier in their history they were considered one and the same. Mineralogy had developed into a study of the materials, characteristics, properties and chemistry of various objects that naturally form part of the earth's crust. Using this image, Adolf Knop [1828-1893] did not think minerals belonged to a special class of materials, but should in fact be treated as objects of general inorganic chemistry. He therefore called his mineralogy "Anorgranographie" and wrote a textbook on the subject that he titled, *System the Anorganographie* (Leipzig, 1876). In this work, he gives a classification of minerals together with all the chemical elements known at the time, as well as some naturally occurring organic compounds. Although this volume does propose a mineral system based on chemistry, it is so mixed with the other materials Knop includes as to be almost unrecognizable.

### 9.7.99 Conclusion: 19th Century

**REWORK:** Notwithstanding the work of the learned exponents of the Natural History method, the later views of Berzelius, as adopted and modified by Rammelsberg, Naumann, Dana and others, now prevail among students of mineralogy, with whom the results of the chemical analysis of species are generally considered as of paramount significance. While hardness, specific gravity, crystalline form and optical characters assume a secondary value inr classification, and are regarded as important chiefly in connection with determinative mineralogy. The conception of a true natural method, which, although but partially understood, was at the basis of the system of Mohs, has been generally lost. The order which the naturalist finds in the organic is no longer apparent in the inorganic world, as presented in modern mineralogical text-books. This state of things has contributed not a little to the comparative neglect into which systematic mineralogy has of late years fallen.

As to the complete divorce between physical and chemical char-acters in the study of mineral species, maintained by Werner, Mohs, and his followers, there seems to have underlaid it the notion of framing a system which, as in botany and zoology, shall be available for the purposes of determination without the destruction of the individual. It is to be noted, however, that characters dependent upon chemical differences, such as the presence or absence of certain acids, alkaloids and groups of essential oils, are not without significance in determining the natural affinities of plants. Moreover, that as we descend the scale of being from the highly organized forms of the animal and vegetable world to the simple crystal or the amorphous colloid mass, the external characters which serve to show likeness and difference become fewer, and are often obscure and ill-defined. Again, a natural system is not one subordinate to the end of identifying species, but should consider objects in all their alliances and relations. Such a system, as long since defined by John Ray, is one which neither

brings to-gether dissimilar species nor separates those which are nearly allied y and the most important resemblances and differences in the mineral kingdom are, in many cases, those which can only be determined by chemical investigation.

If, however, we regard as mistaken those who in their search after a natural system in mineralogy have rejected the aid of chemistry, it must be said, on the other hand, that the chemical mineralogists who, disregarding the relations of density and hardness, or relegating them to a secondary rank, build systems on the results of chemical analysis, are false to chemical science itself. There exist, in fact, inherent and necessary relations between the physical characters and the chemical constitution of inorganic bodies which serve to unite and reconcile the natural-historical and the chemical methods in mineralogy. A physico-chemical study of the mineral kingdom, having in view these relations, will enable us, while remaining faithful to the traditions of Werner and of Mohs, to frame a classification which it is believed will merit the title of a Natural System in Mineralogy.

## 10.0 Nomenclature[1077]

**REWORK:** Generally working in tandem with attempts to systematize mineralogy were reformations of the nomenclature to fit the new classification system. Mineralogical nomenclature is the collection of names used to identify all of its species. Together with other terminology that describes information specific to mineralogy, it is a thread that binds the science together, allowing mineralogists to pass information between themselves and to define their study. Without this facility discoveries could not be conveyed to later generations and the science would stagnate. This was recognized early on as a necessary ingredient to building mineralogy. As Agricola noted in the fifteenth century, "He who wishes to instruct others should bestow upon each separate thing a definite name."[1078] The study of nomenclature therefore provides interesting insights into the issues, discoveries, and development of the science.

Although several attempts have been made throughout time to systematize mineralogical nomenclature, none ever held on for very long. This is anomalous to the other natural history studies of botany and zoology, which have had a systematic nomenclature since 1740 and the time of Linneaus. This probably results from a two differences. First the number of species in the mineral realm is insignificant compared to those contained in these other studies,[1079] and thus the need for a systematic structure to name the species is minimized. Second, minerals unlike the species of its natural history cousins, botany and zoology, are not propagated through biological reproduction, and thus there are no evolutionary mutations. Rather, minerals are formed by chemical interactions with in the earth and unlike a living body which will attempt to form new species to match its environment, one mineral species simply stops being deposited when environmental conditions

[1077] Further historical information may be found in: M.P. Crosland., *Historical studies in the language of chemistry*. Cambridge, Massachusetts, Harvard University Press, 1962. xvii, [1], 406 p., plates, illus., biblio., index. • F.M. Endlich., "On some interesting derivations of mineral names," *The American Naturalist*, **22** (Jan., 1888), p. 21-32 and **22** (Feb., 1888), p. 128-142. • H. Hugo A. Francke., *Ueber die Mineralogische Nomenclatur. Eine ausführliche Erörterung der für die Bildung wissenschaftlicher Mineralnamen in Betracht kommenden Grundsaetze und Regeln*. Berlin, R. Friedländer & Sohn, 1890. x, [2], 124 p. [Study of mineralogical nomenclature, which contains much of historical interest.] • Franz von Kobell., *Die Mineral-Namen und die Mineralogische Nomenklatur*. München, J.G. Cotta'schen Buchhandlung, 1853. [4], 160, [4] p. [A study of mineralogical nomenclature, including much on its history of development.] • Austin F. Rogers., "The nomenclature of minerals," *Proceedings of the American Philosophical Society*, **52** (1913), p. 606-615.

[1078] Georgius Agricola., *De Re Metallica*, translated by Herbert and Lou Hoover. London, 1912, p. 3n.

[1079] In 2006, there are 4,124 valid mineral species, versus hundereds of thousands of botanical and zoological species. A single tree in New Zealand has been shown to be home to over 2,200 insect species. J.A. Mandarino (See, "Old mineralogical techniques," *Canadian Mineralogist*, **15** (1977), p. 1-2) summarized the number of new species introduced during every twenty-year period from 1800. From 1800 through 1819 the number was 87. In the period from 1820 through 1919 every twenty-year interval recorded on the average about 185 new minerals. In recent years the number has greatly increased. From 1920 through 1939 there were 256 new minerals described; from 1940 through 1959 there were 342; and in the thirteen-year period from 1960 through 1973 there were 575.

change while conditions may make another possible.

One of the most noticeable things about the names of minerals is the lack of uniformity in their terminations. While the large majority of them end in -ite, there are many with -ine, while -ane, -ase, -ose, and several others have often been used. It is to be regretted that early on the termination -ite was not universally adopted. It has the sanction of antiquity, for it was used by the old Greek writers in the forms -ites or -itis, as in ??????, 'hematite,' and ???????, 'alabaster.' The Romans adopted the ending from the Greeks and Pliny gives siderites, 'lodestone,' steatitis, 'soapstone,' molochites, 'malachite,' and many others. These forms are undoubtedly the source of the termination -ite now in use, as they are the earliest known terminations in mineral names.

Unfortunately, an old science like mineralogy is dominated by tradition and custom, and these factors have had considerable influence in retarding a more discerning approach to mineral nomenclature. There are two contrasting tendencies in mineralogical nomenclature, the rational and the irrational.

Rational mineral names convey information about the mineral itself. Although in the minority, many such names exist, as will become clear later. Names based on chemical compositions, crystal forms and habits, colors, lusters, and other properties, all illustrate rational nomenclature. On the other hand irrational names communicate very little or nothing about the mineral. The influence of Abraham G. Werner [1750-1817] at the end of the eighteenth century contributed to the predominance of the irrational principle when he began to name minerals for various persons. His method established a historical perspective in mineral names, but the names bore little or no relationship to the minerals themselves. In some instances the name indicates the discoverer or first analyst of the mineral. Names based on geographical localities convey slightly more information about the mineral, depending upon the kind of locality name used. The name franklinite, for Franklin, New Jersey, is considerably more specific than a name like brazilianite, for the entire country of Brazil. Now minerals named to honor an individual are the predominate method for naming with over half of the valid speices being named after an individual or individuals.

Along with the introduction of new minerals, old mineral names are constantly being reexamined for validity and many have been discredited. Names are usually discarded when it is shown they apply to minerals which are either identical to or are chemical variants of well-established species. These names then become obsolete, and are not to be used again. Of the more than 15,000 mineral names in the older literature,[1080] only around 4,100 are for valid species while some additional ones have been retained for use as varietal names (for example, the varieties of quartz known as agate, amethyst, carnelian, chalcedony, and citrine). The total number of mineral species is relatively small compared to the number of known and theoretically possible synthetic inorganic substances. Povarennykh[1081] indicates that by the year 1971 there were 1916 more or less firmly established mineral species. Furthermore, at that date there were 148 minerals which had not been examined adequately or were doubtful regarding their status as species, although probably about half of these would prove to be genuine species with further study.

Reference...[1082]

Reference...[1083]

## 10.1 Ancient Names[1084]

**REWORK:** The earliest names recorded in history are necessarily those that were applied

[1080] Aballain, M., Chambolle, P., Derec-Poussier, F., Guillemin, C, Mignon, R., Pierrot, R., and Sarcia, J. A. Index Alphabetique de Nomenclature Mineralogique. Paris: Bureau de Recherches Geologiques et Minieres, 1968.

[1081] Povarennykh, A. S. Crystal Chemical Classification of Minerals, Volumes I-II. New York: Plenum Press, 1972.

[1082] Thomas Sterry Hunt., *Mineral Physiology and Physiography* ... Nomenclature and terminology... 1886 or 1891.

[1083] H.S. Washington., "Suggestions for mineralogical nomenclature," *American Journal of Science*, 4th series, **33** (1912), p. 137.

[1084] Glotz, *Mineralnamen*, 1972.

to the earliest known mineral. Consequently the native metallic elements, copper, silver and gold, and the precious and semi-precious stones are the minerals with the oldest nomenclature. In Egypt before 4000 B.C.E. these substances were given terms based upon their obvious physical properties. The oldest name for gold in Egyptian hieroglyphics is nub, which is also the term referring 'to smelt.'[1085] This name perhaps originated in connection with the gold mines of Nubia. Other hieroglyphics denote gold from different origins: 'gold of the water,' 'gold of the mountain,' 'gold of Coptos,' etc.[1086] The Egyptian term for silver, hetch or hd, means 'white' and is also distinguished from different localities. Quartz and other silicates were also identified in ancient times.[1087]

The civilizations of Babylonia and Assyria also developed their rudimentary nomenclatures along similar lines.[1088] Thus the name for silver means 'white brillance.[1089] Animals and plants were also named by the Assyrians.[1090]

The early Greek writers to convey a quality, constituent, use or locality of a stone would append the ending -itis or -ites. The use of the termination -lite, in German -lith, from the Greek ??????, 'a stone,' ought here to be mentioned, as it was a genuine attempt to iutro duce a distinguishing mark for mineral names, which, if successful, would have been of great benefit to mineral nomenclature, as bringing in the desirable element of uniformity. This also comes from antiquity, being found in the Greek. But it never came into general use, aud in later years is seldom used except for euphony. There is an erroneous impression that the termination -ite is derived from this, which, as we have seen, is not the case, as it is a much older form.

Such names were given by the ancients as noting some property or use of the mineral, or sometimes designating its source, or the locality from which it was derived; as ???????, a mineral from Magnesia. Or, to speak of those already mentioned, aiudrtrr1 is a mineral resembling blood, so called from the color of its powder; dXafiaartzii, a mineral from which a vessel called an alabastron was cut; siderites, from aidr/poS, 'iron,' because it contains it; steatitis, from orearoS, 'of fat,' because it feels greasy; aud molochites, from ?????, 'mallows,' alluding to its green color. In the 5th edition of his great work on Mineralogy, Prof. J. D. Dana makes an attempt at uniformity of nomenclature by changing the terminations of many names into ite, particularly those ending in -ine, only leaving those unchanged which had come into too general use in the language to be so treated. So we have galenite, alabaudite, pyrrhotite, and periclasite, instead of galena, alabandine, pyrrhotine, and periclase. Some of these changes have been generally adopted.

Names have been given to minerals since antiquity. Originally, names were derived from geographical localities or from mineral properties, either real or imaginary. Many of these ancient names have long etymologies and their earliest origins are obscure. With the advancement of the science of mineralogy, an ever increasing number of names appeared in mineralogical literature.

Some ancient and classical mineral names have origins which have been traced to the languages of India, especially to Sanskrit. In most of these cases the names were adopted in turn by the Greeks and then by the Romans. Some of these names include opal (meaning precious stone), sapphire, tincal (meaning borax; the name of the mineral tincalconite is derived from this), and corundum (meaning ruby).

## 10.2 Middle Ages[1091]

[1085] Crosland, *Historical Studies*, 1962, p. 66.

[1086] Crosland, *Historical Studies*, 1962, p. 66.

[1087] André Cailleux., "L'Histoire des mots 'silex' et 'pierre'," *Cahiers Géol. Thoiry*, no. 18 (1953), p. 165-167. [Brief remarks on the history of the Roman and French usage of the words silex (flint) and pierre (stone).]

[1088] Reginald Campbell Thomson., *Dictionary of Assyrian chemistry and geology*. Oxford, Clarendon Press, 1936. xlviii, 266 p.

[1089] Crosland, *Historical Studies*, 1962, p. 67.

[1090] F. Delitzsch., *Assyrische Tiernamen mit einem assyrischen und akakdischen Glosser*. Leipzig, 1874. 196 p.

[1091] Further historical information may be found in: G. Friess., *Edelsteine im Mittelalter Wandel und Kontinuität in ihrer Bedeutung durch zwölf Jahrhunderte* (in Aberglauben, Medizin, Theologie und Goldschmiedekunst). Hildesheim, Gerstenberg, 1980. 207 p.

**REWORK:** As all scientific works were written in Latin up to a very recent date, and as there was no chemistry to show differences in composition, there was no real progress in mineralogy. External characters alone were used as means of distinguishing minerals from each other, and those that looked alike must necessarily be classed together. Pliny's names were sufficient for all the uses of the science down to the sixteenth century. There was hardly a name added, even by Agricola, whose large works were published 1529 to 1546. The name fluor is perhaps the only new one he gives, and that he did not originate, but took from the vocabulary of the furnace men, who used fluorspar in smelting their ores. Certain minerals in general use had their common names in various languages, but there were few of them.[1092]

### Alchemy

One potenial source for new mineral names were the alchemists of the age, however, few of the mineral names given by them have survived in their original application. Perhaps because of the allegorical and secretive nature of their texts, the names they did emplly did not come into general use. Marcasite, for instance, now designates a compound of sulphur and iron, while it was originally used for bismuth (marcasita argentea). Besides the planets, which held special importance for the alchemists, mythological deities were called upon to furnish names for the ever-growing list of mineral compounds. Thorite perpetuates the name of the mighty Scandinavian god, the son of all-powerful Odin and the Earth. Interestingly, Quicksilver (mercurius vivus) has been handed down unchanged, although this is now considered a synonym for native mercury and not a valid mineral name.

The names of some well-known minerals were adopted by European mineralogists from Arabic words which were transmitted in the Middle Ages. In some cases these terms have long etymologies traceable to the early Persians. Realgar comes from Rahj al ghar, powder of the mine; talc comes from talq, meaning talc. Marcasite and trona apparently also have Arabic origins. The mineral serendibite is derived from Serendib, an old Arabic name for Ceylon. Arabic mineral names which were apparently borrowed from Persian include borax, lazulite, and zircon.

## 10.4 Scientific Nomenclature Develops

**REWORK:** As the science of mineralogy developed, especially in terms of understanding its chemistry, it became apparent that the haphazard nomenclature that had developed over the centuries was proving to be an obstacle to further advance. Prominent mineralogists began to suggest through their books and other publications reforms to overhaul the names of the species and anchor it to some form of structure.

In 1728 John Woodward published a work entitled *Fossils of all Kinds Digested into a Method, Suitable to their Mutual Relations and Affinity*, but it is a description from external characters only, and can hardly be called a scientific treatise. He proposed a series of changes including the names of minerals, but they were not adopted.

Carl Linneaus found that there was a great confusion of terminology and he later complained that a botanist was not respected unless he published long lists of synonyms. At the age of thirty, Linnaeus published his *Critica Botanica* (1737) in which he set out to establish the principles on which a satisfactory botanical nomenclature could be founded. Linnaeus could not, of course, pretend to have any special authority. His only excuse for taking it upon himself to suggest a complete reform of botanical terms was that a start had to be made somewhere. He is often quoted as a precedent for the reforming of nomenclature in other studies such as mineralogy, geography, medicine, pharmacy and chemistry.

In fact, Linnaeus attempted to reform mineralogical nomenclature by applying a system of binomial nomenclature to their names. This was introduced in the famous *Systema Naturae* and continued to be employed by it originator and an army of other mineralogists. It

[1092] J.G. Haditsch and H. Maus., *Alte Mineralnamen im deutschen Schrifttum*. Herausgegeben, O.M. Friedrich. Leoben, Institut für Mineralogie und Gesteinskunde, 1974. [6], 312 p. [Published as *Sonderband 3 des Archives für Lagerstättenforschung in den Ostalpen*.]

was not until the mid-nineteenth century that it was finally conceeded that the principals applied to plants and animals could not be easily applied to minerals, and the binomial system finally was extinguished in mineralogy.

The first mineralogist that really was modern in his approach to the study was the Swedish mineralogist Johan Gottlob Wallerius, who in 1747, published all that he knew about minerals in his *Mineralogia*. It is arranged on a scientific plan, and gives us the earliest systematic description of minerals.

In Sweden, Cronstedt had anonoymously published his *Försök til Mineralogie* (1758). Cronstedt, another Swedish chemist, ten years later gave us a work of much greater value, as he brought in chemical relations, as far as was possible in the crude state of that science. But few new names were added, for the study was still largely from the external side, and new species could not be recognized. Although he was obviously interested in the naming of mineral substances, he exercised caution in naming substances that were not fully understood.

> As soon as we are arrived to such a pitch, as by the examination of a mineral body to discover or know all its constituent parts, and can assert with certainty that it can be no further decompounded by any method hitherto known; then such a body ought, according to the intention of this Essay, to receive its specific name, and not before; for otherwise it will be vague and trivial.[1093]

Cronstedt described all minerals by a Swedish name followed by a Latin translation or description.[1094]

terra calcarea Acido Vitrioli saturata seu mixta = calcium sulphate (gypsum)

Ferrum Sulphure saturatum = ferrous suphide

Acidum Salis Communis Argento saturatum Argentum Acido Salis solutum et mineralisatum = silver chloride

Cronstedt's work appears to have influenced Bergman, who in 1775 used expressions of the type: Acidum Salis saturated with Magnesia, Magnesia saturated with the aerial acid.[1095] In other writings, however, Bergman used abbreviated phrases involving the use of the past participle and he referred to two compounds (magnesium chloride and carbonate) as magnesia salita and magnesia aerata respectively.[1096]

Cronstedt's book was translated into French in 1771 by Monnet who appears to have been impressed[1097] by Cronstedt's insistence on the enumeration of the constituent parts of salts. He describes many salts by two names, the first being its common name and the second relating to its constitution, e.g. sei de glauber, ou combinasion de l'acide vitriolique avec l'alkali minéral; mine d'argent corné, ou combinaison de l'argent avec l'acide marin. The same method of nomenclature was adopted by Brongniart in his *Tableau Analytique des combinaisons ... de différentes substances* (Paris: 1778).

### 10.4.2 Werner and his School[1098]

**REWORK:** Werners times became designations of the minerals after their discoverers usually, those also such followed however later after persons, which did not have any relationship with the mineralogy (alexandrite), furthermore names, which referred to the discovery site, whereby in the consequence also cases occurred, how that of the Milarit, whose discovery site was intentionally wrongly indicated by the first collecting tank of this mineral. Other mineral names come into use refer to conspicuous outside characteristics, others to components, like Kobaltin, Zinkit etc., while naturally for the elementary minerals the names of the elements concerned served. With the progressing of the chemical knowledge of the minerals certain names proved very practically, e.g. to that of the Smaltins for those isomorphic

[1093] F.A. Cronstedt, *An Essay towards a System of Mineralogy*, translated by Gustav von Engström. Second edition. (London: 1772) p. xx.

[1094] F.A. Cronstedt, *Försök til Mineralogie* (Stockholm: 1758), pp. 18, 184,123, 159.

[1095] T.O. Bergman, *Königl. Schwedischen Akademie der Wissenschaften*, **37** (1775), p. 19, 21.

[1096] T.O. Bergman, *Nova Acta Reg. Societatis Scientiarum Upsaliensis*, **2** (1775), p. 118-35.

[1097] Monnet refers to Cronstedt frequently in his *Nouveau Système de Minéralogie* (Bouillon: 1779).

[1098] Horst Franke and Volker Wahl., "Zur Entstehung des Mineralnamens 'Göthit'," *Goethe Jahrbuch*, **95** (1978), p. 241-247.

mixtures of $FeAs_2$ $CoAs_2$ and $NiAs_2$ in which the cobalt prevail, which the Chloantit for the nickel-richer, which cannot be naturally separated in systematics from those. Since however a general principle for the designation of the minerals does not exist, then this question does not have any meaning for the development of the mineralogy as science.

With the discovery of oxygen in 1776, and the real beginning of the science of chemistry, a more correct basis for the differentiation of mineral species was found. This was aided by the application of scientific crystallography, the first edition of de L'Isle's work appearing in 1772, and the second, in four volumes, in 1783. From this date new names were given to minerals as the result of more extended research in this branch of study, and one of the first of these was prehnite, given by Werner to a mineral brought from the Cape of Good Hope by Colonel Prehn, and hence named after him. Werner first announced the name in his lectures in 1783, as he himself states later, but it was not published for several years.[1099] In 1789 there is an article in the *Journal de Physique*, by Sage, objecting to the use of names of persons for minerals, the text for which is this name of Werner's. But the name has kept its place, and is now the accepted one for the species. Other names, given about the same time after persons, are witherite, after Dr. Withering, who first described it, and torberite, later changed to torbernite, after Torbern Bergmann, its first analyst. This latter mineral has gone through various vicissitudes as to its name, and a list of them, as an illustration, may not be out of place here; they are taken from the 5th edition of Dana's Mineralogy, p. 585: Mica viridis, 1772; Chalkolith, 1788; Torberite, 1793; Uranglimmer, 1800; Torbernit, 1803; Uranite, 1814; Uranphyllit, 1820; Cupro-uranit, 1865.

Several attempts have been made to give systematic names to minerals on some such principle as is used in other branches of nuatural science, but not one of them has been generally adopted, and all have by degrees been dropped. One of the earliest of these was by Sir John Hill, in his of *Fossils*, London, 1748. He divides minerals into numbered classes, and orders, and under these into named genera and species. His genus names are many of them new, but are sometimes older names modified to suit his system. For instance, Marmora, for the marbles. A good example of his new names, and also of the way in which species were multiplied when only external characteristics were considered, is in the order of Inflammables. The 3d class is called Phlogonise, and under this we have as the 1st genus, Pyricubia, and under this two species: 1st, Pyricubiuin maximum foliaceum, and 2d, Pyricubium solidum minus. The first of these species is simply those cubical crystals of iron pyrites which are striated by an oscillation toward a hemitetrahexahedron, and the second is the unstriated crystals of the same. Octahedral pyrite is made another genus, and dodecahedral is still another. Several more genera are made trom what is now the one species. This system never came into general use, and Hill himself gives it up and adopts one much more simple in his later work entitled *Fossils Arranged according to their Obvious Characters* (London, 1771).

### 10.4.3 Reflections of Chemical Reform[1100]

**REWORK:** The nomenclature of chemistry and mineralogy has always been intertwined because minerals are naturally occuring chemical compounds, and the first source for many experimental compounds were pulverized minerals. Thus when chemical nomenclature was being reformed, it is only to be expected that mineralogy would be also. One pressing need for the reform of chemical nomenclature was brought about by the great increase in the

[1099] John Sinkankas., "Letters to the editor." *Mineralogical Record*, **1** (1970), p. ??-??.: Notes that a footnote in the second supplement to Urban Friedrich Benedict Brückmann's, *Abhandlung von Edelsteinen* (1st ed., Braunschweig, 1757.; 2nd edition, 1773) and more specifically, the second supplement thereto, entitled *Gesammlete und einige Beiträge ... Zwote Fortsetzung* (1783). I found what is undoubtedly one of the earliest references to prehnite in print, and which is. furthermore, based on actual conversations between Brückmann and Prehn.

[1100] Further historical information may be found in: M.P. Crosland., *Historical studies in the language of chemistry*. Cambridge, Massachusetts, Harvard University Press, 1962. xvii, [1], 406 p., plates, illus., biblio., index.

number of substances known. This is particularly evident in the latter half of the eighteenth century when several new elements were discovered. Reform of the chemcial nomenclature lead to attempts to reform mineralogical nomenclature as well.[1101]

With the discovery of oxygen in 1776, and the real beginning of the science of chemistry, a more correct basis for the differentiation of mineral species was found. This was aided by the application of scientific crystallography, the first edition of de L'Isle's work appearing in 1772, and the second, in four volumes, in 1783.

Names based on the chemistry of a mineral in contrast to most other mineral names, which say very little or nothing about the nature of the mineral itself, some names have been derived from the chemical components of the minerals. Although practically none of these reveal the complete chemical composition they do indicate the more important elements and occasionally give additional information.

Bergman ... [1102]

Numerous chemical prefixes are used in mineral species names. Prefixes such as arseno-, bismuto-, calcio-, chalco-, cupro-, ferri-, ferro-, kali-, lithio-, magnesio-, mangano-, natro-, phospho-, plumbo-, sidero-, thoro-, urano-, and others, are very common. Frequently these are affixed to earlier mineral names to show structural and chemical relationships between the minerals. Sometimes the prefixes are combined with other Latin or Greek terms to form new names. Names like kaliophilite and natrophilite are formed from a prefix plus phil, which means friend of hence: friend of potassium (kalio-) and friend of sodium (natro-) respectively. Chalcophyllite, from phyllon meaning leaf plus chalco for copper, giving copper leaf, alludes to the mineral's composition and micaceous structure; chalcotrichite in similar fashion means, literally, copper hair, alluding to the mineral's composition and exceedingly long, hairlike crystals. Siderophyllite, iron leaf, and siderotil, iron fiber, have similar meanings.

Most varieties of mineral species are a result of relatively minor chemical deviations from the ideal composition of the mineral. To indicate such varieties a chemical adjective may be used to modify the mineral species name. Using this scheme such variety names as the following have been used: ferroan dolomite, mercurian tet-rahedrite, zincian spinel, cobaltoan siderite, potassian natroalulte, aluminian chalcosiderite. In the last three examples the chem-adjectives modify mineral names which are themselves derived ¿in common chemical prefixes. Palache, Berman and Frondel l ;uss the use of chemical adjectives, originally proposed by jhaller,2 in the naming of mineral varieties. They also present complete list of the chemical adjectives which can be used in iis manner, and discuss how different valencies can also be indi-ited.

Probably the greatest influence Latin has had in forming mineral names is in chemical prefixes. Mineral names involving the following are at least in part of Latin origin: alumino-, argento-, auri-, calcio-, carbo-, cupro-, ferri-, ferro-, fluor-, nitro-, plumbo-, and stanno-. The use of these prefixes, as well as similar Greek prefixes, to modify older mineral names, or to form new mineral names was part of the chemical reform.

Some examples of mineral names derived directly from Latin designations for the common metallic elements are argentite (for silver), cuprite (for copper), and stannite (for tin).

### 10.4.4 Nomenclature Reformation

**REWORK:** With the introduction of the 'New Chemistry' at the end of the 18th century a vast movement was made to reform the old chemical nomenclature. Since the chemical study of minerals paralleled chemical studies the attempt to reform spilled over into mineralogy. ...

René Just Haüy [1743-1822], the famous French crystallographer and mineralogist, introduced many mineral names which, although they were often derived from Greek terms, did not usually end with the common suffixes. Dana was critical of Haüy's departure from the common use of the -ite suffix; he wrote: "For-

[1101] W.A. Smeaton., "The contributions of P.-J. Macquer, T.O. Bergman and Guyton de Moreavu to reform chemical nomenclature," *Annals of Science*, **10** (1954), p. 87-106.

[1102] Crosland, p. 146-148.

getting that the unity of law which he [Haüy] had found in nature should be a feature of scientific language, he gave to his names the following terminations..." Following this is a list of various inconsistent mineral names invented by Haüy, including terms such as amphibole, anatase, diallage, epidote, harmotome, pleonaste, pyroxene, and sphene.

Many other mineral names, especially those of ancient origin and derived from various languages, do not have consistent endings. Such names include beryl, borax, cinnabar, corundum, litharge, opal, quartz, realgar, talc, and many others. Likewise mineral names derived from Old English (Anglo-Saxon) have inconsistent endings, for example, gold, ice, iron, lead, lime, spar, and water.

In 1802 Richard Kirwan ...[1103]

Berzelius, dass recognized chemical names for die minerals suited does not seyen, it wants however, dass each name in's latin had to be able to be translated. it complains already 1814 about die seeks to give new names. to modify " I can differently than hoechlich to disapprove die ungezaehmte searches many mineralogen, name well-known fossil, because dadurch das study is very much made more difficult - which has die mineralogy won durch die permutation des named ichthyophthalm approximately apophyllit, da die characteristic, which last meaning arranged, with many other minerals occurs to diese searches der name change lies sometimes only in des of author longing, der science something of its own mitzutheilen, which gift however, if it far anything on itself does not have, into everyone is able stands and with dem reader rarely das excited, which perhaps intended der good-natured givers." (*Schweigger's Journ.*, **11** (1814), p. 222.)[1104]

Robert Hare ...[1105]

In 1820 Prof. Mohs brought out a small book entitled *The Characters of the Classes, Orders, Genera, and Species; or the Characteristic of the Natural History System of Mineralogy.* Intended to enable students to discriminate minerals on principles similar to those of Botany and This system is more fully presented in his larger work of 1822-4, lated by Haidinger in 1825. He uses genus and species names for each mineral, and sometimes adds a third for more exact distinction. Under the genus garnet he gives Pyramidal Garnet, or idocrase; Dodecahedral Garnet, or true garnet; and Prismatoidal Garnet, or staurolite. Dioptase becomes Rhombohedral Emerald-Malachite. This system was quite popular for a time, and had several imitators. Prof. C. U. Shepard adopts Mohs's system, and in the erst edition of his mineralogy, 1832-5, he not only uses his names, but extends the system still further. He, however, gives first the common or trivial names, as they are called, and always uses them in speaking of species. Microlite is the one new species of his own noted in this book, which under the system he calls Octahedral Baryte, and similar names are carried all the way through. None of these names are mentioned in his third edition, 1852-7.

William Whewell ...[1106] more Whewell references ...[1107]

In 1836 Prof, J. D. Dana read a paper before the New York Lyceum of Natural History, entitled 'A New Mineral Nomenclature', in which he presents a complete arrangement according to the Natural History method, and gives some very good reasons for its adoption. This system is carried out in full in the first edition, 1837, of his *Mineralogy.* He uses in general two names for eacli mineral, as Andalusius prismaticus

[1103] Richard Kirwan., "On chymical and mineralogical nomenclature," *Transactions of the Royal Irish Academy*, **8** (1802), p. 53-?.

[1104] Jons Jakob Berzelius., "Essai sur la nomenclature chimique," *Journal de Physique*, **73** (1811), p. 253-286. • *ibid.*, "Versuch einer lateinischen Nomenclatur für die Chemie, nach electrisch-chemischen Ansichten," *Annalen der Physik (Gilbert's)*, **42** (1812), p. 37-89.

[1105] Robert Hare., "Some remarks on the nomenclature of the celebrated Berzelius, with some suggestions repecting its amendment," *Philadelphia Coll. Pharm. Journ.*, **5** (18??), p. 209-17. • *ibid.*, "A letter to Berzelius on chemical nomenclature," *American Journal of Science*, **49** (18??), p. 249-57.

[1106] William Whewell., *An essay on mineralogical classification and nomenclature; with tables of the orders and species of minerals.* Cambridge, Mass., 1828.

[1107] P.J. Wexler., "The great nomenclator. Whewell's contributions to scientific terminology," *Notes & Queries*, n.s., **8** (1961), no. 1, p. 28-32.

for andalusite, but he gives the common name first in all cases. In his second edition, 1844, he retains these Latin names as the scientific ones, aud as necessary to .'a systematic idea of the science,' but adds, p. 135, 'the shorter trivial names should however be retaiued, as more convenient for common use.' In the third edition, 1850, however, Prof. Dana discards the whole system, not even retaining the names as synonyms. A system of arrangement is adopted that was understood to be temporary, while at the end of the work a chemical classification is suggested. In the later editions this last has been perfected, aud we now have an arrangement easy of reference and answering all purposes of classification, but from which all traces of the double Latinized forms of the Natural History methods have disappeared. This or some similar system is now generally followed by writers on mineralogy, much to the satisfaction of those who use their works.

Breithaupt: some mineralogen believed to have to introduce latin a nomenclature so more Necker, to more Glocker, Breithaupt and Dana, which convince however a better, it soon again auf gave die name Necker's (*Le Règne Minéral*, 1835) it are mostly latinisirungen under which: nickelocrum, sperkisa, leberkisa, blenda, ziguelina, cuprous mica, ferric spathum; others are breithauptia, hausmannia, klaprothia, leadhillia etc. die nomenclature breithaupt's (*Complete Manual of Mineralogy*, 1841) are systematic. thus e.g. die are called species des genus: thiodinus.

1. thiodinus strontosus, coelestin.
2. thiodinus syntheticus, kalkschwerspath.
3. thiodinus barytosus, baryte.
4. thiodinus plumbosus, bleivitriol.

Breithaupt is perhaps der only mineralog, which das is multicolored multicolored raw ore der mineral name not yet enough. " everywhere, he says, hears one complaints over die multiplicity of der names, and doch is not it damit by any means so badly one compares only aim at in order to calm down darueber, die nearly in's infinite going synonymie der planting name etc. dass at present a systematic nomenclature die name confusion to only carry can and above all die durchfuehrung of a suitable specifischen nomenclature sey, more haidinger emphasized (*Manual of Determinitive Mineralogy*, 1845.) it supplemented die existing gaps and similar to dem past use name, which refers to possibly a characteristic of a mineral, der Greek language inferred I has, as much I skillfully, die past principien der nomenclature in my writing: " the mineral names and die mineralogical nomenclature. 1853." lit up and me substantially to more haidinger attached, just as running God among other things

In 1847 Glocker published his work entitled *Generum et Specierum Mineralium Synopsis*. This is perhaps the most successful attempt at a systematic nomenclature that has been made. He uses in general a Laiiuized form of the common name for the name of each species, with some descriptive word added. For varieties he adds a third word, as is common in other branches of natural history For instance, under Granatus, garnet, he gives three species: 1st, Granatus nobilis, precious garnet; 2d, Granatus. hyacinthinus, cinnamon garnet; and 3d, Granatus vulgaris, common garnet, and under the latter he uses for varieties the terminations fuscus, niger, viridis, flavus, and albidus. The work is in Latin, thus going back to the style of the scientific books of the last century. Recently Prof. T. Sterry Hunt has devised a new Natural System, suggested indeed as early as 1853, but as he gives few new species names a discussion of it would be out of place here. His work is, however, exceedingly interesting, and will well repay examination by those who care to go further into that side of the general subject.

Some odd references ...[1108]

In 1876 Prof. C. U. Shepard published a *Catalogue of Minerals found within about 75 miles of Aniherst College, Mass.*, in which he proposed that the names of all acknowledged mineral species, except those of the elements and a very few more, shall uniformly end in -ite, and that the termination -ine shall as uniformly be used for all variety names, and

[1108] Dufour, É., "Essai d'une nomenclature chimique et mineralogique," *Nantes, Ann. Soc. Acad.*, **41** (1870), pp. 247-55.

those specific character is not fully settled. Accordingly, he gives us e, serpentite, wadite, orthoclasite, spodumenite, epidotite, and many similar changes, while marmolite, picrolite, nacrite, and others are made to end in ine, marmoline, picroline, nacriue. It is hardly necessary to say that these suggestions have not been generally or fully accepted.

Terry S. Hunt ...[1109]

Full information about many names is easily obtained. But with reference to a considerable number of names the information wanted is not easy to obtain, and in some cases perhaps it cannot be found at all. When it is not given in Dana's Mineralogy, the student may be sure that he must . search to find it. This is particularly true of obsolete names, information about which must often be sought in the earlier volumes of scientific journals.

### 10.4.5 Physical Properties

### 10.4.6 Localities

### 10.4.7 Personal Names

### 10.4.8 Dictionaries

Numerous dictionaries appeared to list the mineralogical nomenclature.

An early dictionary of miners terms including names of minerals was published by William Hooson in 1747 as *The Miners Dictionary.*[1110] It was based on his 40 years of personal experience in the mines of England.

In a handy volume, William Humble brought together the terminology and nomenclature of geology and mineralogy.[1111]

In 1871, Friedrich August Eckstein wrote on the philosophy of nomenclature development.[1112]

At the end of the 19th century, Albert Huntington Chester compiled an important dictionary of mineral names, giving extensive information on the etymology and uses the various mineral names had been put to.[1113] It is a valuable compilation being to its time the most comprehensive history of the names of minerals ever published. The text lists in an alphabetical sequence nearly five thousand names that have been applied to minerals. Included are minerals still considered actual species, as well as those that are varieties or that have through history become discredited or had the priority for their name, given to another researcher. All except about one hundred and fifty entries contain a complete reference to the original authority and a derivation of the the names meaning. At the conclusion of the text there is a very useful index to the various mineralogists that have named minerals contained within the body.

Emile Chanel published in 1897 a useful dictionary for French geological and mineralogical terms and stratigraphic units. It includes some historical references.[1114]

## 11.0 Regional Histories

In this section are contained short histories outlining the development of mineralogy

[1109] T.S. Hunt., "The classification and nomenclature of metalline minerals," *American Philosophical Society*, **??** (1888), 12 p.

[1110] W. Hooson., *The Miners Dictionary. Explaining Not only the Terms used by Miners, But also Containing The Theory and Practice Of that most Useful Art of Mineing, [*sic*] More especially of Lead-Mines. I. How a Gentleman may know whether He has Mines in his Land, or not. II. How he may know the cheapest and best Way to come at Them. III. The Method of carrying Them on, in order to make them Profitable Works. Together with a large Account of all necessary Materials that are required, conducive thereto. The Whole being ver great Use to all Miners and Gentlemen, who have Miners in their own Lands, and all such as are concern'd in Mines. Being Observations made by the Author, from more than Forty Years Practice and Experience, at the Mines in the High and Low Peak in Derbyshire, Shropshire, South and North-Wales, and the North of England.* London, 1747. [230] p.

[1111] William Humble., *Dictionary of geology and mineralogy, comprising such terms in botany, chemistry, comparative anatomy, conchology, entomology, palæontology, zoology, and other branches of natural history, as are connected with the study of geology.* London, Published by Henry Washbourne, 1840. [Useful soruce for definitions of obsolete terms.]

[1112] Friedrich August Eckstein., *Nomenclator philologorum.* Leipzig 1871. vii, 656 p. [Reprinted, Hildesheim, G. Olms, 1966.]

[1113] A.H. Chester, *A Dictionary of the Names of Minerals including their History and Etymology.* New York, 1896. xxxviii, 320, [2], 16 p.

[1114] Emile Chanel., *Dictionnaire de géologie, étymologie, paléontologie, minéralogie a lusage des elèves des lycées et collèges, des écoles normales primaires ... Par Emile Chanel.* Bourg, Imprimerie du "Courrier de l'Ain," 1897. [8], 259, [1] p.

and crystallography in the countries of the world. These histories will be useful in giving a perspective to the development of the mineralogical sciences in a limited area. Further, the countries are grouped together, more or less, geographically so that patterns of mineralogical research might be better seen.

### Topographical Mineralogies

Topographical mineralogies relevant to the country will be listed at the end of each regional history. These publications, either in book or article form, describe the minerals of a specific region and are known generally as a 'topographical mineralogy.' They are useful in showing the mineral species that are known to occur in a specific area and are generally useful for the mineral detective in showing what other species might yet be discovered by looking at the relation of the known minerals. Additionally topographical mineralogies, especially the older ones, sometimes yield valuable historical and bibliographical information, especially in terms of when a specific locality was discovered.

Ancient books describing minerals would necessarily describe specimens from specific regions because the author's seldom compared minerals from one locality and another. However, these descriptions were integrated into the body of the text and not a true topographical study. In fact the appearance of true topographical mineralogies was a rather late development. Agricola for example had described species from the mines of Bohemia as a colliery to his works in mining and mineralogy. But as a separate entity works cataloging the mineral species found in with in a single mine or district or listings of localities with sublists of species found at the localities did not come into wide use until the 18th century.

Regions of Germany were the first to be described by a topographical mineralogy. Fridericus Lachmund's *Oryktographia Hildesheimensis* (1669) is so far as is known the first work of a topographical nature. Johann Heinrich Schütte in his *Opyktographia Jenensis, sive Fossilium et Mineralium* wrote about the fossils and minerals found in the area around Jena in 1720. Mineralogical maps, the precursor to geological maps, were also very useful in locating mineral resources with in a country of region.[1115]

By the 19th century, topographical studies became more common. Karl Cäsar von Leonhard compiled a dictionary of mineral localities with his *Handbuch einer allgemeinen topographischen Mineralogie* (1805-9). Johann Carl Freiesleben wrote extensively about the minerals and mining of the area around Saxony in his *Beyträge zur mineralogischen Kenntniß von Sachsen* (1817). Later, Gustav von Leonhard would write the first dictionary of topographcial mineralogy, *Handwörterbuch der topographischen Mineralogie* (1843). More importantly for the development of the science circumstances of mineralogical development at specific locations in the form of paragenetic studies became important. Thus lists and descriptions of minerals from a locality became more common through out the century. It was due to the increased number of works enumerating the mineralogy of an area, it was possible at the end of the 19th century for C. Hintze to include extensive lists of localities for the species he described in his important *Handbuch der Mineralogie*. Crystallographers also took note of the different crystal forms observed from different localities, and their numerous works form the basis for V. Goldschmidt's illustrations in his important *Atlas der Krystallformen* (1913-23).

## 11.1 General (Worldwide)

Topographical Studies

1805 Karl Cäsar von Leonhard., *Handbuch einer allgemeinen topographischen Mineralogie*. Frankfurt am Main, 1805-1809. 3 vols. [4], iv, 479, [1], 8 p.; [6], 568, [8] p.; [6], 432 p. [General handbook to the topographical mineralogy.].

1843 Gustav von Leonhard., *Handwörterbuch der topographischen Mineralogie*. Heidelberg, 1843. xii, 593,

[1115] V.A. Eyles., "Mineralogical maps as forerunners of modern geological maps," *The Cartographers Journal*, **9** (1972), p. 133-5. • H.A. Ireland., "History of the development of geologic maps," *Geological Society of America, Bulletin*, **54** (1943), no. 9, 1227-80. • J. Marcou and J.B. Marcou., *Mapoteca geologica Americana. A catalogue of geological maps of America (North and South), 1752-1881. In geographic and chronological order*. Washington, Goverment Printing Office, 1884. 184, [2] p., index. [Published as: *Bulletin of the U.S. Geological Survey*, no. 7. This useful reference describes 923 maps.]

[3] p. [Early attempt at giving a list of mineral localites through out the world.].

2004 Jan H. Bernard and Jaroslav Hyršl., *Minerals and Their Localities*. Prague, Granit, s.r.o., 2004. 807 p., color illus. [A massive work giving the localities for over 4200 mineral species.].

## 11.2 Europe

### Topographical Studies

1928 F. Slavík and L.J. Spencer., "Place names of mineral localities in central Europe," *Mineralogical Magazine*, **21** (1928), p. 441-479. [Alphabetical index of all the place-names in twelve languages.].

## 11.2.1 United Kingdom[1116]

## 11.2.1.1 England[1117]

### Topographical Studies

1804 James Sowerby., *British Mineralogy*. London, 1804-1817. 5 vols. 1160 p., illus., color.

1845 W. Adam., *The Gem of the Peak, Review of the Geology of Derbyshire, Catalogue of Rocks and Minerals*. 4th edition, London, 1845. 464 p.

1858 R.P. Greg and W.G. Lettsom., *Manual of Mineralogy of Great Britain and Ireland*. London, John Van Voorst, 1858. 483 p., illus. Reprinted, with supplementary lists 1-4, Kent, Lapidary Publications, 1977.

1868 T.M. Hall., *The Mineralogist's Directory: or a guide to the Principal Mineral Localities in the United Kingdom and Ireland*. London, Edward Stanford, 1868. 180 p.

1882 J.G. Goodchild., "Contributions towards a list of minerals occurring in Cumberland and Westmoreland," 3 parts, *Transactions of the Cumberland Association for the Advancement of Literary Science*, **7, 8, and 9** (1882-1885), 67 p.

1898 Leonard J. Spencer., "Supplementary list of British Minerals," *Report of the British Association for the Advancement of Science*, 1898, p. 875-877; reprinted in *Geological Magazine*, **6** (1899), p. 75-77. Second supplementary list ,1931, L. J. Spencer, *Report of the British Association for the Advancement of Science*, 1932, p. 378. Third supplementary list, 1958, *Mineralogical Magazine*, **31** (1958), p. 787-810. Fourth supplementary list, 1978, P.J. Embrey, *Mineralogical Magazine*, **42**, p. 169-177. Eighth supplementary list, 1990, G. Ryback and P.C. Tandy, *Mineralogical Magazine*, **56** (1990), p. 261-275.

1941 A.W.G. Kingsbury., "Mineral localities on the Mendip Hills," *Mineralogical Magazine*, **26** (1941), p. 67-80, map.

Cornwall

1758 William Borlase., *Natural History of Cornwall*. Oxford, W. Jackson, 1758. 326 p.

1871 J.H. Collins., *A Handbook to the Mineralogy of Cornwall and Devon*. 2 parts, London and Truro, 1871. 2nd edition, Truro, 1892. [Reprinted, Truro, Cornwall, D. B. Barton, 1969. 180 p., plus addenda and illus.].

1911 J.H. Collins., "List of minerals found in Cornwall and Devon, with notes supplementary to the author's 'Handbook'," *Journal Royal Institute Cornwall*, **18** (1911), p. 425-461.

1987 Peter G. Embrey and R.E. Symes., *Minerals of Cornwall and Devon*. London, British Museum (NH) and Mineralogical Record Inc., Tucson, Az., 1987. 154 p.

Derbyshire

1802 John Mawe., *The Mineralogy of Derbyshire*. London, 1802. 226 p., map.

Devonshire

1868 T.M. Hall., "On the mineral localities of Devonshire," *Transactions Devonshire Association*, **2** (1868), p. 332-346; **3** (1869), p. 75-78.

Jersey Island

1961 A.E. Mourant., "The minerals of Jersey," *Bulletin Society Jersiaise*, **18** (1961), p. 69-90, illus.

Midlands

1881 C.J. Woodward., "The minerals of the Midlands," *Midland Naturalist*, **4** (1881-1882), p. 87-90, 112, 162-165, 183-186, 217-220, 257-260.

## 11.2.1.2 Scotland[1118]

### Topographical Studies

1800 Robert Jameson., *Mineralogy of the Scottish Isles; with Mineralogical Observations in a Tbur through different parts of the mainland of Scotland*. London, 1800. 2 vols., 243 p.; 291 p.

1874 M.F. Heddle., "The county geognosy and mineralogy of Scotland," *Mineralogical Magazine*, 1874, p. 2-5.

1901 M.E. Heddle and J.G. Goodchild., *The Mineralogy of Scotland*. Edinburg, 1901. 2 vols., 461 p., 120 plates. [Reprinted, with minor alterations, 1923.].

1982 H.G. Macpherson and A. Livingstone., " A glossary of Scottish mineral species 1981," *Scottish Journal of Geology*, **18** (1982), p. 1-47.

1983 A. Livingstone and H.G. MacPherson., "5th Supplementary list of British minerals, Scottish," *Mineralogical Magazine*, **42** (1983), p. 99-105.

1993 A. Livingstone., "Glossary of Scottish mineral species; an update," *Scottish Journal of Geology*, **29** (1993), pt. 1, p. 87-101.

[1116] Further historical information may be found in: John Smith Flett., *The first hundred years of the Geological Survey of Great Britain*. London, H.M. Stationery Office, 1937. 280 p., 13 plates. (one folding, including portraits.) [Standard history of the the Geological Survey of Great Britain.]

[1117] Further historical information may be found in: Micael P. Cooper., *Robbing the Sparry Garniture. A 200-year history of British mineral dealers*. Tucson, The Mineralogical Record, 2006. iv, 358 p., illus., biblio. [An amazing compilation of information available no where else on dealers of minerals in Great Britain.] • James William Davis., *History of the Yorkshire Geological and Polytechnic Society, 1837-1887*. London, 1889. 498 p. • W. Campbell Smith., "Early mineralogy in Great Britain and Ireland," *Bulletin of the British Museum (Natural History), Historical Series*, **6** (1978), 49-74, biblio.

[1118] Further historical information may be found in: John Smith Flett., "The first geological map of Scotland," *Transactions of the Edinburgh Geological Society*, **13** (1936), pt. 3, p. 291-303. • Carl Friedlander., "Early notes on Acadian geology," *Dalhoesie Review*, **26** (1957), no. 4, p. 378-382. • Thomas H. Holland., "Geology in Edinburgh at the beginning of the nineteenth century," *Transactions of the Edinburgh Geological Society*, **13** (1935), pt. 2, p. 202-209. • Alec Livingstone, *Minerals of Scotland: Past and present*. Edinburgh, National Museums of Scotland Publishing Limited, 2002. xvi, 212 p., illus., index, biblio. [A truly wonderful compilation presenting in one long section a biographical study of the collectors and collections of Scottish minerals, which includes many portraits and much history.] • Peter Macnair., *History of the Geological Society of Glasgow, 1858-1908*. Glasgow, 1908. 372 p. • James Ritchie., "Natural history and the emergence of geology in the Scottish Universities," *Edinburgh Geological Society, Transactions*, **15** (1952), p. 297-316.

2002 Alec Livingstone, *Minerals of Scotland: Past and present*. Edinburgh, National Museums of Scotland Publishing Limited, 2002. xvi, 212 p., illus., index, biblio. [A truly wonderful compilation presenting in one long section a biographical study of the collectors and collections of Scottish minerals, which includes many portraits.].

### 11.2.1.3 Wales

Topographical Studies

1928 F.J. North., *Geological maps, their history and developement with special reference to Wales*. Cardiff, National Museum of Wales, 1928. 133 p., illus.
1988 Richard Bevins., "6th supplementary list, Welch," *Mineralogical Magazine*, **52** (1988), pt. 1, p. 121-124.
1994 Richard Bevins., *Mineralogy of Wales*. Cardiff, National Museum of Wales, 1994. 146 p., illus. [In this detailed look at the minerals of Wales, the species are arranged in alphabetical order with descriptions and localities, and some locality maps.].

### 11.2.1.4 Ireland[1119]

Topographical Studies

1832 C.L. Giescke., "An Irish mineralogy; or, a list of simple mineral substances hitherto discovered in Ireland," (pp. 201-208) in C.L. Giescke., *A Descriptive Catalogue of . . . Minerals in the Museum of the Royal Dublin Society*. Dublin, 1832.
1858 R.P. Greg and W.G. Lettsom., *Manual of Mineralogy of Great Britain and Ireland*. London, John Van Voorst, 1858. 483 p., illus. Reprinted, with supplementary lists 1-4, Kent, Lapidary Publications, 1977.
1862 R.J. Griffith., "Catalogue of the several localities in Ireland where mines or metalliferous indications have hitherto been discovered up to 1854, arranged in counties," *Journal Geological Society of Dublin*, **9** (1862), p. 140-155. [Separately reprinted, 1884..
1878 S. Haughton, "On the mineralogy of the counties of Dublin and Wicklow," *Sci. Proc. Roy. Dublin Soc.*, new series, **1** (1878), p. 183-189.
1902 H.J. Seymour., "Preliminary list of minerals occurring in Ireland," *Rep. Brit. Association Advancement Science, 1902*, p. 598-599.; Supplementary list 1903, *Rep. Brit. Association Advancement Science, 1904*, p. 671.
1987 I.C. Legg and J.F. Pynne., *Mineral localities in the Dalriadan and associated igneous rocks of County Donegal, Republic of Ireland and of Northern Ireland*. Dublin, Geological Survey of Ireland, 1987. 87 p., 2 maps, 4 maps.
1988 G. Ryback, R. Nawaz, and E. Farley., "Supplementary list of British minerals," 7th, Irish, *Mineralogical Magazine*, **52** (1988), pt. 2, 267-274.

## 11.2.2 Iberian Peninsula

### 11.2.2.1 Spain (España)[1120]

Topographical Studies

1899 F. Barras De Aragon., *Apuntes para una descripciôn geologico mineralogica de la provincia de Sevilla*. Palencia, 1899. 359 p.
1902 A. Tenne and S. Calderon., *Die Mineralfundstätten der Iberischen Halbinsel*. Berlin, A. Asher, 1902. 353 p.
1910 S. Calderon., *Los Minérales de Espana*. Madrid, Imprenta De Eduardo Arias, 1910. 2 vols., 985 p., illus.
1912 A. Boscä y Seytre., *Memoria Mineralogico-minera de la Provincia de Teruel*. Teruel, 1912. 95 p.
1918 P. Castro Barea., "Minérales de Andalucia: Especies y localidades no citados, existentes en el Museo de Historia Natural de la Universidad de Sevilla," *Bol. Soc. Espan. Hist. Nat.*, **18** (1918), p. 314-319.
1920 L. Tomas., "Els minerals de Catalunya," *Tréb. Inst. Catalana Hist. Nat. for 1919-20*, 1920, p. 129-357.
1942 D.A. Marin., "Recursos minérales de Espana," *Bol R. Soc. Geogr. Madrid*, **78** (1942), p. 85-183, 234-283.
1979 E. Galan Huertos and S. Mirete., *Introducción a los Minérales de España*. Madrid, Espafia, Institute Geologico y Minero, 1979. 420 p.
1981 J.M. Mata Perello., *Eh Minerals de Catalunya*. University of Barcelona, 1981. 5 vols., illus.
1985 J.M. Mata Perello., "Inventario mineralogico de la Tierra de Alcaraz," *Cantil Revista de Geologia*, **17** (1985), 45 p., illus.
1985 J.M. Mata Perello., "Inventario mineralogico de las Tierras de Albacete y de La Roda," *Cantil Revista de Geologia*, **14** (1985), 30 p., illus.
1985 J.M. Mata Perello., "Inventario mineralogico de la Tierra de Almansa," *Cantil Revista de Geologia*, **15** (1985), 31 p., illus.

[1119] Further historical information may be found in: Gordon L. Herries Davies., "Geology in Ireland before 1812: a bibliographical outline," *The Western Naturalist*, **7** (1978), p. 79-99. • *ibid.*, "The history of Irish geology" (pp. 303-315), in: Charles H. Holland, ed., *A Geology of Ireland*. Edinburgh, Scottish Academic Press; New York, Wiley, 1981. x, 335 p., frontispiece, 191 illus. • *ibid.*, *North from the Hook: 150 years of the Geological Survey of Ireland*. Dublin, Geological Survey of Ireland, 1995. xi, 342 p., illus. • Patrick N. Wyse Jackson., "Fluctuations in fortune: Three hundred years of Irish geology," (pp. 91-114) in: Helena C.G. Chesney and John Wilson Foster, eds., *Nature in Ireland: A scientific and cultural history*. Dublin, McGill-Queen's Press, 1998. xii, 662 p., illus. [ISBN 0773518177.] • C.W.P. MacArthur., "Mineralogical and geological travellers in Donegal," *Donegal Annual*, no. 39 (1987), p. 39-57. • Ross, Helena C.G., "The development of natural history in early 19th-century Ireland," (pp. 13-27) in: Alwyne Wheeler, James H. Price, eds., *From Linnaeus to Darwin: Commentaries on the history of biology and geology*. London, The Society, 1985. v, 214 p. • W. Campbell Smith., "Early mineralogy in Great Britain and Ireland," *Bulletin of the British Museum (Natural History), Historical Series*, **6** (1978), 49-74, biblio.

[1120] Further historical information may be found in: J.L. Amorós., "The introduction of Werner's mineralogical ideas in Spain and the Spanish colonies of America," *Freiberger Forschung - H*, **C-223** (1967), p. 231-236. [Describes the spread of Werner's theories in Spain and its colonies.] • P. Fallot., "Les progres de la Geologie en Espagne depuis cent ans," *Mem. de la Real Academia de Cie., Exactas, Fisicas y Naturales, Madrid*, **11** (1950), p. 115-156. • Juan López de Azcona and José M.Y. Pardo. "Contribución a la historia de la geología y minería Españolas," *Madrid, Instituto Geológico y Minero de España*, 1964, p. 107-245, illus. • L. Mallada., "Los progresos de la Geologia en Espana durante el Siglo XIX," *Discurso de reception en la Real Academia de Ciencias Exactas. Fisicas y Naturales*, Madrid, 1897, p. 5-66. • Miguel Calvo Rebollar., *Bibliografía fundamental de la antigua mineralogía y mineria Españolas*. Prólogo de Antonio Canseco Medel. Madrid, 1999. [1]-259 p., illus., index. [Historical bibliography of mineralogy and mining in Spain. Supplements and continues Maffei & Rua Figuera, *Bibliografía Mineral*, 1871-2. An excellent reference.]

1985 J.M. Mata Perello., "Inventario mineralogico de la Tierra de Alcaraz," *Cantil Revista de Geologia*, **17** (1985), 45 p., illus.

1988 M. Calvo, J. Besteiro, E. Sevillano, and A. Pocovi., *Minérales de Aragon*. Zaragoza, Mira Editores, 1988. 142 p., illus., color.

### 11.2.2.2 Portugal[1121]

Topographical Studies

1902 A. Tenne and S. Calderon., *Die Mineralfundstätten der Iberischen Halbinsel*. Berlin, A. Asher, 1902. 353 p.

1909 A. d'O Bello., "Minéraux portugais," *Bull. Soc. Portugaise Sci. Nat.*, **2** (1909), p. 272-280; **4** (1911), p. 68-78; **6** (1913), p. 90-103.

1928 A. Mario de Jesus, A. Viana, and R. Cavaca., "Minerais de Portugal continental," *Publ. Museu Commercial*, Lisboa, 1928, 29 p.; (1930) p. 33-112, illus.; also *Comm. Serv. Geol. Portugal*, **16** (1930), p. 51-152.

1984 C. Rewitzer and N. Röschl., "Portugal: Fundortbeschreibungen und Reisetips," *Lapis*, **9** (1984), no. 12, p. 13-30.

n.d. J.P. Gomes., "Mineraes descobertos em Portugal," *Comm. Dir. Trab. Geol. Portugal*, **3** (19—), p. 99-209.

### 11.2.2.3 Canary Islands[1122]

Topographical Studies

1987 P. Roth., *Kanarische Inseln*. Berlin, Sammlung geologischer Führer, 1987. 226 p., illus.

2002 Juan Carlos Carracedo and Simon Day., *The Canary Islands*. Harpenden, England, Terra, c2002. viii, 294 p., illus., maps. [Geology of the Canary Islands.; ISBN 1903544076.].

## 11.2.3 Central

### 11.2.3.1 Austria (Österreich)[1123]

Topographical Studies

1859 Viktor von Zepharovich., *Mineralogisches Lexicon für das Kaiserthum Österreich*. Vienna, Wilhelm Braumuller, 1859. 3 vols. Volume 1 (1859) 627 p.; volume 2 (1873) 436 p.; volume 3 (1893), edited by F. Becke, 493 p. Reprinted 1985, 1542 p.

1993 Reinhard Exel., *Die Mineralien und Erzlägerstatten Österreichs*. Vorkommen, Verwendung und wirtschaftliche Bedeutung. Geologie der Lagersätten. Geschichte der mineralogischen Erforschung Österreichs. Sammlungswesen und Mineralienhandel, mit Lexikon der Mineralien Österreichs. Wien, R. Exel, 1993. 447 p., illus. [Apparently a topographical study of the minerals and ores of Austria, including sections on the history of the mineralogical research, collections and dealers, and a lexicon of the minerals.].

1994 A. Witern., *Taschenbuch der Mineralien Funstellen Mitteleuropas: Österreich*. Haltern, Germany, Bode Verlag, Gmbh., 1994. 228 p., illus.

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[1121] Further historical information may be found in: J. Carrington da Costa., "Do Conhecimento geologico de Portugal Continetntal," *Porto, Fac. Ciênc., An.*, **26** (1941), no. 4, p. 206-229, geological map. [Outlines the history of geological studies in Portugal beginning with the earliest writings.] • M. Portugal Ferreira., "A mineralogia em Portugal no século XIX" (**2**, pp. 665-709), in: J.P. Peixoto, et al., *História e Desenvolvimento da Ciência em Portugal i Colóquio até ao Século XX, Lisboa, 15 a 19 de Abril de 1985*. Lisboa, Adademia das Ciências de Lisboa, 1986. 2 vols. 1407 p. [Mineralogy in Portugal in the 19th century.] • *ibid.*, "O museu de história natural da Universidade de Coimbra (Secção de Mineralogia e Geologia) desde a reforma Pombalina (1772) até à República (1910)," *Memórias e Notícias*, no. 110 (1990), p. 53-76. [History of the Museum of Natural History at the University of Coimbra.] • *ibid.*, "Pioneiros da Mineralogia em Portugal," *Colóquio Ciências*, **4** (April, 1992), no. 10, p. 79-98. Fundação Caalouste Gulbenkian, Lisboa. [Pioneers of mineralogy in Portugal.]

[1122] Further historical information may be found in: C.M. García Cruz., "The origin of the Canary Islands: A chronology of ideas and related concepts from Antiquity to 2000," INHIGEO, Sidney, 2001. 13 p.

[1123] Further historical information may be found in: J. Blaas., *Kleine Geologie von Tirol*. Eine Übersicht über Geschichte und Bau der Tiroler und Vorarlberger Alpen für Schule und Selbstunterricht. Innsbruck, Wagner, 1907. viii, 152 p., one colored map, 22 illus., 12 plates. • Reinhard Exel., *Die Mineralien und Erzlägerstatten Österreichs*. Vorkommen, Verwendung und wirtschaftliche Bedeutung. Geologie der Lagersätten. Geschichte der mineralogischen Erforschung Österreichs. Sammlungswesen und Mineralienhandel, mit Lexikon der Mineralien Österreichs. Wien, R. Exel, 1993. 447 p., illus. [Apparently a topographical study of the minerals and ores of Austria, including sections on the history of the mineralogical research, collections and dealers, and a lexicon of the minerals.] • Helmut W. Flügel., *Geologie und Paläeontologie an der Universität Graz, 1761-1976*. Graz, Austria, Akademischen Druck- und Verlageanstalt, 1977. xii, 134 p., 41 photos, folding diagram, biblio., index. • Peter Goller and Gerhard Oberkofler., *Mineralogie und Geologie an der Leopold-Franzens-Universität Innsbruck (1867-1945)*. Innsbruck, Im Kommissionsverlag der Wagner'schen Universitätsbuchhandlung, 1990. 60 p., illus. Published as *Forschungen zur Innsbrucker Universitätsgeschichte*, **15**. [History of the teaching of mineralogy and geology in Innsbruck, Austria.] • Franz Ritter von Hauer., *Die Geologie und ihre Pflege in Österreich, ein Vortrag*. Die Feierliche Sitzung der Kaiserlichen Akademie der Wissenschaften am 31 Mai 1861. Wien, 1861. [Probably contains some historical information on the development of geology in Austria.] • Elise Hofmann., "Die Geologische Bundesanstalt in Wien," *Geologiska Föreningens i Stockholm Förhandlingar.*, **58** (1936), no. 406, Heft 3, p. 409-418. [A brief history of the directors and work of the Austrian Geological Survey.] • Harald Lobitzer and Pavol Grecula., *Geologie Ohne Grenzen Festschrift 150 Jahre Geologische Bundesanstalt*. Wien, Geologische Bundesanstalt, 1999. 460 p., illus. [This work contains contributions on the history of geology in Austria and its former empire in southern lands.; ISBN 3853160042.] • H. Meixner., "Geschichte der mineralogischen Erforschung Kärntens," *Carinthia II, Klagenfurt*, **61** (1951), 16-35. [History of mineralogy in the Austrian province of Carinthia.] • H. Michel., "Die Mineralogie in Österreich und die Mineralogische Gesellschaft in Wien. Festausgabe zum 50 Jahrigen Bestand der Wiener (seit 1946 österreichischen) Mineralogischen Gesellschaft. (Gastein - Heft)," *Mitteilungen des Österreichen Mineralogische Gesellschaft*, no. 112 (1951), p. 1-12. [Description of the first fifty years of the Austrian mineralogical society.]

Alps

1975 H. Weninger., *Die Alpinen Kluftmineralien der Österreichischen Ostalpen*. Heidelberg, Publicazione Spéciale délia VFMG, 1975.

Carinthia (Kärnten)

1870 H. Hofer., "Die Mineralien Kärntens," *Jahrbuch Nat. Hist. Landesmus*, **10** (1870), 84 p. [Also separatedly issued.].

1884 A. Brunlechner., *Die Mineralien des Herzogthumes Kärnten*. Klagenfurt, 1884. 136 p. Additions, *Jahrbuch Nat. Hist. Landesmus*, **17** (1885), p. 227-229; **22** (1893), p. 186-194.

1957 H. Meixner., "Die Minerale Kärntens, I Teil, Systematische Übersicht und Fundorte," *Carinthia II*, **21** (1957), 147 p., illus.

1986 J. Mortl., "Zur Mineraltopographie Kärntens," *Die Karinthin*, **95** (1986), p. 415-422.

Lower Austria

1937 A. Sigmund., *Die Minerale Niederösterreichs*. Second edition, Wien & Leipzig, 1937. 258 p.

Salzburg

1859 L. Köchel., *Die Mineralien des Herzogthumes Salzburg*. Wien, 1859. 249 p. [Reprinted, 1980s.].

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### 11.2.3.1 Hungary (Magyarország)[1126]

The beginning of Hungarian mineralogy is closely linked to the general development of the science in Europe and the large degree of mining that occurred in the country. Located in the eastern portion of Europe and bodering the Asian continent, the territory of Hungary was controlled for a long period by the Austro-Hungarian Empire. Consequently, much of the mineralogy carried out in the area was performed by Austrian or German trained scientists.

In the sixteenth century there were scant mentions of Hungarian minerals in the literature. Georg Agricola mentioned the mines and minerals of Hungary in his famous *De Re Metallica* (1556). In 1549 Georg Wernher published his *De Admirandis Hungariæ Aquis Hypomnemation*, which is one of the first natural history books by a Hungarian author with sections on the mineralogy of the region.

By 1617, Márton Szepsi Csombór authored a dissertation on the metals and their ores that were recovered in Hungary.[1127] It is among the first natural history disseratations written by a Hungarian student. Athanasius Kircher includes mineralogical reports form Hungary in his famous *Mundus Subterraneaous*.[1128] Until the end of the sixteenth century, mineralogy was generally taught as a special section of general physics, generally referred to as 'physica specialis.' When János Púsaházi wrote his physics textbook *Philosophia Naturalis* in 1667, he included chapters on mineralogy. This was the first physics text written by a Hungarian, and was used through out the universities of the country. In 1672, Johann Paterson Hain was the first Hungarian to publish a paper on the minerals of his homeland.[1129] In 1673, the English physician Edward Browne published an account of his 1669 travels through Hungary and the adjacent lands. He includes a number of mineralogical notes and descriptions of things he observed.[1130] Jacobus Tollius of Amsterdam also published an account of his travels in Hungary undertaken in 1660 and 1687.[1131] It too included descriptions of the regions mineral resources.

István Csiba gives a physical description of the natural history of the mountains of Hungary including their mineral resources in his 1714 disseration, *Disseratatio Historio-Physica de Montibus Hungariæ*. In 1717,

[1126] Further historical information may be found in: Johann Böckh., "Kurze Geschichte der Entwickelung der Geologie in Ungarn vom Jahre 1774-1896," *Földt. Közl.*, **27** (1897), p. 109-122. [Short history of geological research in Hungary, 1774 to 1896.] • Marc. Vinc. Lipold., "Der Bergbau von Schemnitz in Ungarn," *Jahrbericht. der K.K. Geologische Reichsanstalt*, **17** (1867). [This review of mining in Schmnitz contains on pages 321-329 a bibliography of 64 titles ordered chronology 1558-1866.] • Bajos Loczy., "Beköszöntö – Amtsantritt," *Hungary, K. Ung. Geolo. Anst.* (Magyar K. Földt. Int.), Jber. 1933-35, **1** (1939), p. 1-80. [In Hungarian and German, this is a series of biographical sketches of Hungarian geologists, together with an account of the history of the Hungarian Geological Survey.] • Gábor Papp., *A Magyar Topografikus és Leíró Ásványtan Története*. Published as *Topographia Mineralogica Hungariae*, **7** (2002), 444 p., index, illus., biblio. [History of the topographical and descriptive mineralogy of Hungary.] • Sándor Koch., *A Magyar ásványtan Története*. Budapest, Akadémiai Kiadó, 1952. 118 p. [History of mineralogy in Hungary.] • *ibid.*, *Magyarország ásványai szerkesztette Mezösi József*. Budapest, Akadémiai Kiadó, 1985. 562 p., 4 plates. [Topographical mineralogy of Hungary, which contains on pages 13-22 a short history of mineralogy in the country.]

[1127] Márton Szepsi Csombór., *Disputatio Physica de Metallis*. Danzig, 1617.

[1128] Bibliography ...
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[1129] *Ephemerides Medico-Physica Academiæ Naturæ Curiosorum*, 1672.

[1130] Edward Browne., *De re Metallica et Fodinis in Hungariæ*, 1673.

[1131] Jacobus Tollius., *Epistolæ Itinerariæ*, 1700.

Sámuel Klöseri publshed a classic work that dealt with all aspects of Transylvanian gold mining and refining.[1132] That land being considered a part of Hungary at the time.

A massive, scholarly description of the lands through which the river Danube flowed including numerous information on the mines and minerals was authored by Luigi Fernandind Marsigili in 1726.[1133] In his account of mining and mineral resources around the world, Franz Ernst Brückmann gives a detailed account of the mining and minerals of Hungary and Transylvania.[1134] His is also responsible for a series of letters that contain miscellaneous notes of his travels in northern Hungary undertaken in 1724, which includes numerous mineralogical descriptions.[1135]

In recognition of the importance of the Hungarian mines and to make sure the most modern and efficient techniques were used to exploit those resources, the court established in 1735 a two year program of mining and metallurgy at Selmecbánya. In 1763 Nicolaus Jacquin was appointed the first professor of chemistry, metallurgy, and mineralogy at the school. In 1770, the academy expanded to a three year program, thus following the model of established by the Freiberg Bergakademie. In 1767, Janós Fridvaldszky authored the first topographical study of Transylvanian minerals.[1136] Christoph Traugott Delius included descriptions of Hungarian ore deposits and geology in his 1770 *Abhandlung von den Ursprunge der Gebrüge und der darinne befindlichen Erzarden.* The great Italian mineralogist Giovanni Antonio Scopoli became a professor at the mining academy in Schemnitz in 1770. For purposes of instructing his class he authored the first mineralogical textbook designed for higher education in Hungary.[1137] This was quickly followed by his *Principia Minearlogiæ Systematicaæ et Practicæ* of 1772, which is the first systematic mineralogy written by an author living in Hungary. The Transylvanian born Ignanz von Born in 1770 travelled in regions of Hungary and Transylvania, and reported his mineralogical observations in a series of letters that he sent to Johann Jakob Ferber. Collected together and edited these letters were published in 1774 under the title as *Briefe über mineralogische Gegenstände* that was quickly translated into several other languages.[1138]

The Department of Natural History at the University of Nagyszombat was established in 1774 with the Styrian born Mathias Piller being appointed the first professor. His own large collection of specimens, including a significant selection of minerals, formed the basis for the University's collection. Abouth this same time a teaching collection was being formed at Schemnitz. In 1776, the first and only part published of a proposed comprehensive work on the crystallized minerals of Hungary was published by Scopoli.[1139] It is richly illustrated and a loss to science that it was not continued.

In 1778, the third part of Mathias Piller's *Elementa Historiæ Naturalis* appears. It deals with the mineral realm, and, although written in Latin, is the first textbook published in Hungary in the subject. It is targeted at primary and secondary education students.

A topographical outline of Transylvania's mineralogy is given in 1780 in the first volume of the Hungarian born Johann Ehrenreich von Fichtel's *Beyträge zur Mineralgeschichte von Siebenbürgen.*[1140] In that same year, János Molnár published his *Oryctologicon Complexum Historiæ Naturalis Mineralium*, a mineralogical textbook written

[1132] Sámuel Klöseri., *Auraria Romano-Dacia*, 1717.

[1133] Luigi Fernandind Marsigili., *Danubius Pannonico-Mysicus*, 1726.

[1134] Franz Ernst Brückmann., *Magnalia Dei in Locis Subterraneis*, 1727-1734.

[1135] Franz Ernst Brückmann., *Epistolæ Iterineria*, 1728-1741.

[1136] Janós Fridvaldszky., *Mineralogia magni principatus Transsylvaniáé*, 1767.

[1137] *Mineralogische Vorlesungen für die andere Classe der Bergakademie zu Schemnitz*, 1771.

[1138] List translations ...

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[1139] *Crystallographiæ Hungariga*, 1776.

[1140] 1780

in Latin verse. In 1783, Molnár published a brief description of the three kingdoms of nature that included a mineralogical section.[1141] About that same time, the mining councillor at Nagyszeben, Franz Joseph Müller, sent his description along with samples of his newly discovered element tellurium to the great German chemist Martin Heinrich Klaproth in Berlin.[1142]

A former student of Abraham Gottlob Werner and alumnus of the mining school at Freiberg, Ferenc Benkő published in 1784 a Hungarian translation of Werner's fundamental mineralogical work, *Von den ausserlichen Kenntniss der Fossilien*.[1143] He followed this by publishing in 1786 the first systematic mineralogy written in Hungarian. The *Magyar Mineralogia* contains descriptions of the minerals of Hungary described and organized along the theories of Werner. Sámuel Zay published his own *Magyar Mineralogia* in 1791, making it the second systematic mineralogy of Hungarian minerals written in that countries language. Fichtel gives a geological-mineralogical review of the Carpathian Mountains in 1791 in his *Mineralogische Bemerkungen von den Karpathen*.

In 1792, Mathias Piller published his *Collecto Naturalium*, which is the first printed catalog of a Hungarian natural history collection that included minerals. The first textbook in Hungarian on natural history was authored by István Gáti and appeared in 1795 under the title *A Temèszet Historiajá*. It contained a section on mineralogy.

The English naturalist Robert Townson described his 1793 journey through Hungary in his Travels that included many notes about the mines and minerals.[1144] The 1794 field trip examine the mines and minerals of Hungary and Transylvania by the Norwegian scientist Jens Esmark is contained in his *Kurze Beschriebung einer mineralogischen Reise durch Ungarn, Siebenbürgen und das Banat*, which was published in 1798. Lajos Mitterpacher published his *Compendium Historiæ Naturalis*, which was a university textbook of natural history, containing a section on mineralogy. The Hungarian Johann Daniel Haager published in 1796 a small work describing minerals that contained gold that were found in Transylvania.[1145]

By the start of the nineteenth century mineralogical studies of Hungary by native and foreigns was becoming more widespread. The Hungarian professor of natural history Ferenc Benkő published a collection of papers on topographical and systematic mineralogy in 1800.[1146] Basing his study on a 1795 visit, Andreas Stütz wrote a locality monograph of Nagyg with additional informaiton on other Transylvania minerals. Employed as curator of the natural history collections for the Hapsburg court in Vienna, his *Physikalische-mineralogische Beschriebung des Gold- und Silber-Bergwercks zu Szekerembe* was considered authoritative.

The Hungarian, Joseph Schönbauer replaced —— as professor at the —— university. His two volume *Neue Analytische Methode die Mineralien* was an attempt to write a handbook of mineral identification, but although a compentent work, it never enjoyed much success. His son(?), Vinzenz Schönbauer authored a topographical mineralogy of both Hungary and Transylvania.[1147]

In 1810 the Hungarian National Museum established a Department of Natural History that included a mineralogical and geological collection. The 1802 mineral collecting trip by Edward Daniel Clarke through Europe, Asia, and Africa contains descriptions of his adventures in Hungary and Transylva-

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[1142] Wellmann, *Discovery of the Elements*, 7th ed., 1968, ??.

[1143] Ferenc Benkő., *Werner Ábrahám rnak a köveknek és értzeknek külso megismerteto jegyeikrol írott szép és igen hasznos könyvetskéje. Magyar Mineralógia, azaz a kövek és értzek tudománya*, 1784.

[1144] *Travels in Hungary*, 1797

[1145] *Ueber das Vorkommen des Goldes in Siebenburgen*, 1796.

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[1147] *Minerae Metallorum Hungarigiæ et Transylvaniæ*, 1806-1810.

nia.[1148] Topographical mineralogy based on the teachings of Werner was the subject of Christian Andreas Zisper's *Versuch eines topographisch-mineralogische Handbuches von Ungern*. Joseph Jonas published in 1820 his *Ungerns Mineralreich Orycto-Geognotisch und Topographische Dargestellt* that contained a collection of papers on the topographical mineralogy and geology of Hungary. Also in 1820, Johann Reisinger was writing a new university textbook on mineralogy, *Enchiridon Anaorganognosiae* according to Wernerian principals, but it remains unfinished.

In 1818 the French goverment commissioned François Sulpice Beudant to undertake a mineralogical-geological trip through Hungary. The published account of his observations is the famous *Voyage Mineralogiques et Geologiques en Hongerie* that appeared in four volumes with many maps in 1822. The year 1822 also saw the appearance of Mihaly Kováts remarkable minerlalogical dictionary that listed the nomenclature in eight languages, including Hungarian.[1149] In 1830 the Natural History Section including mineralogy of the Hungarian Academy of Sciences (HUNGARIAN NAME) is formed. The department of mineralogy, geology, and palaeontology is in 1843 founded at the Academy of Mining and Forestry at Schemnitz. The first professor is János Pettku.

Antal Mihàlka publised a Hungarian translation of Gustav Rose's *Krystallographie*, which is the first textbook in that language on the science of crystallography.[1150] In 1846, a Polytechnic School is established in Pest. The ciriculum includes mineralogy. A topographical mineralogy of Transylvania is published by Johann Michael Ackner in 1847 to 1855.[1151] In 1848 the Hungarian Geological Society is founded, and in 1849 at the University of Pest, and independent Department of Mineralogy is founded. Just like Scheminitz all geological subjects are taught. THe first professor is József Szabó.

A list of minerals and rocks found in Transylvania is included in Eduard Albert Bielz's *Handbuch der Landeskunde Siebenbürgen* first published in 1857. Enlarged versions of this list are published in subsequent editions of the book published in 1883 and 1889.[1152] In 1859 the first volume of Victor von Zepharovitch's *Mineralogisches Lexicon* appeared.[1153] It was an outstanding attempt to organize the mineralogical localities of the Hapsburg Empire, that prior to World War I included the countries of Hungary and Transylvania. Further volumes appeared in 1873 and 1893.

Jozsef Szabó in 1861 published the first modern university textbook on mineralogy written in Hungarian. Further editions appeared in 1864, 1876, and 1893.[1154] Also in 1861, a former professor of the University of Pest, Karl Ferdinand Peters published a long, authoritative, and still useful locality study of southern Hungary.[1155]

In 1862 Bernard von Cotta's *Die Erzlagerstätten Ungarns und Siebenbürgens* appeared. It reviews the geological processes and mineral paragensis of hte ore deposits of Hungary and Transylvania. Its authority was immediately recognized and a continuation was published in 1864 that described the ore deposits of Banat and Serbia.[1156] A Department of Mineralogy and Geology is established at the Royal József Polytechnic of Buda of which Károly Hofmann was appointed the first professor. The Royal

[1148] Clarke, *Travels*, 1816.

[1149] Mihaly Kováts., *Lexicon Mineralogicum Enneaglottum*, 1822.

[1150] Gustav Rose., *A Jegeczismé Elemei Rose Gustav Után*, 1843.

[1151] *Mineralogie Siebenbürgen*, 1847-1855.

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[1155] Karl Ferdinand Peters., *Geologische und mineralogsche Studien aus dem sudmöstlichen Ungarn*, 1861.

[1156] *Erzlagerstätten in Banat und in Serbien*, 1864.

Hungarian Geological Institute was founded in 1869. In that same year, The Natural History Collection of the Hungarian National Museum was divided into the departments of zoology, botany, and mineralogy. József Krenner was appointed the first professor, and among his first acquisitions was to secure the famous mineral collection of Prince Lobkowitz, which required an act of parliment to secure funds to make the purchase. This added 35,000 specimens to the Museum.[1157]

In 1871, *Földtani Kőzlőny*, the bulletin of the Hungarian Geological Society first appeared. At the founding of the Ferenc József University, the department of mineralogy and geology is established with Antal Koch appointed as the first professor. Also in the 1870's Andor Semsey began his nearly five decade support through donation to the Hungarian National Museum. Working together with József Krenner they build one of the world's finest mineral collections.[1158]

In 1882, Mike Tóth puhlished his *Magyarország Ásványai* the only complete topographical mineralogy of pre-world war Hungary. This was followed by Antal Koch's *Erdély ásványainak kritikai átnézete* that is the first critical, modern review of the minerals of Transylvania. It was published in 1884-1885. To show off the mineral wonders of Hungary, in 1886 Jozsef Szabó set up a large mineralogical display at the newly built Műzeum Körűt. A large exhibit of minerals is installed in 1900 at the Royal Hungarian Geological Institute, and in 1911, the first issue of the mineralogical periodical, *Műzeumi Főzetek* appeared. It was a short lived publication, with the last number being published in 1919.

After the redistribution of the lands of the former Austro-Hungarian nation following World War I, various possessions were transferred to other regions. The Ferenc József University was moved to Budapest in 1919, and in 1919, after the creation of independent Czechoslovakia, the Mining and Forestry School was transferred from Selmecbßnya (Schemnitz) to Sopron.

Topographical Studies

1776 J.A. Scopoli., *Crystallographia Hungarica*. 1776. 139 p., illus.

1786 F. Benkő., *Magyar Minealogia az a' Kovek's Ertzek Tudomanya*. Budapest, 1786. Reprinted 1986.

1817 C.A. Zipser., *Versuch eines Topographisch Mineralogischen Handbuchs von Ungern* [sic]. Odenburg (Sopron), 1817. 471 p.

1882 M. Tóth., *Magyarország ásványai* [The Minerals of Hungary with special regard to the Determination of their Occurrences]. Budapest, 1882. 565 p.

1966 Sándor Koch., *Magyar ásványtan* [Minerals of Hungary]. Budapest, Mezosi Joszef, 1966. 563 p., illus. Second edition, 1985.

1969 Laszlo Trunkó., *Geology of Hungary*. Revised and expanded English edition of: *Geologie von Ungarn*, 1969. Berlin, Gebrüder Borntraeger, 1996. viii, 464 p., illus., maps.

1979 S. Huber and P. Huber., "Mineralien aus Ungarn," *Lapis*, **4** (1979), p. 21-24, illus., color.

1985 Sándor Koch., *Magyarország ásványai szerkesztette Mezösi József*. Budapest, Akadémiai Kiadó, 1985. 562 p., 4 plates. [Topographical mineralogy of Hungary, which contains on pages 13-22 a short history of mineralogy in the country.].

1991 E. Balázs and S. Szakáll., *Mineral Rarities of Hungary*. Budapest, Fine Arts Publishing House, 1991. 83 p.

### 11.2.3.1 Switzerland (Helvetia)[1159]

Topographical Studies

[1157] Gábor Papp and H. Vincze-Szeberényi., "The Duke Lobkowitz Collection," *Annals of the History of Hungarian Geology, Special Issue*, **3** (1991), 63-6.

[1158] Destroyed in WWII?.

[1159] Further historical information may be found in: V. Gramlich and H. Grimmer., "The history of crystallography in Switzerland," *Chimia*, **55** (2001), p. 484-6. [A short review of the development of crystallography in Switzerland and of the Swiss Society for Crystallography.] • Albert Heim., *Geologie der Schweiz*. Leipzig, 1919. ["Einleitung," **1**, p. 1-36 contains a good history of geological research in Switzerland.] • Johann Georg Koenigsberger., *Ueber alpine Minerallagerstätten*. München, Verlag der Königlich Bayerischen Akademie der Wissenschaften; in Kommission des G. Franz'schen Verlags, 1917-19. 3 vols. [Published as: *Abhandlungen der Bayerischen Akademie der Wissenschaften*, **28** (1917), no. 10, [1]-35 p., **28** (1918), no. 11, [1]-131 p., map and **28** (1919), no. 12, p. [1]-108. The work contains a useful section called "Alte Litteratur" in the third volume.] • F. de Quervain., "200 Jahre Mineraltopographie der Schweiz," *Schweiz. Strahler*, rbf 3 (1975), no. 11, p. 455-8. • Jean-Pierre Portmann., "Notice historique de géologie neuchâteloise," *Eclogae Geologicae Helvetiae*, **59** (1966), no. 1, p. 5-19, illus. • *ibid.*, "Deux siècles de Géologie à Neuchâtel," *Gesnerus*, **32** (1975), pts. 1-2, p. 45-60. • Philippe Roth., *Minerals first discovered in Switzerland and minerals named after Swiss individuals*. Achberg, Kristallografik Verlag, 2006. [Besides valuable biographical notes, the book also contains "A brief history of mineralogy in Switzerland."] • Joachim Schroeter., "Frühe Beiträge zur Erforshung der alpinen Kluftmineralien," *Schweizerische mineralogischen und petrographische Mitteilungen*, **29** (1948), p. 215-21. [A history of research on alpine minerals, found in the Alps of Switzerland.] • Bernhard Studer., *Geschichte der physischen Geographie der Schweiz bis 1815*. Bern/Zürich, 1863. ix, 671 p.

1775 G.S. Gruner., *Versuch eines Verzeichnisses der Mineralien des Schweizerlandes*. Bern, 1775. 201 p., maps.
1866 Gustav Adolph Kenngott., *Die Minerale der Schweiz, nach ihren eigenschaften und fundorten ausführlich beschrieben*. Leipzig, W. Engelmann, 1866. x, 460 p., diagrams.
1934 F. de Quevrain and M. Gschwind., *Die nutzbaren Gesteine der Schweiz*. Bern, 1934. 468 p. [Reprinted, 1969.].
1966 M. Weibel., *A Guide to the Minerals of Switzerland*. New York, Interscience, , 1966. 123 p., illus., color.
1973 M. Weibel., *Mineralien der Schweiz*. Stuttgart, Birkhauser, 1973.
1973 Hans Anton Stalder, F. de Quervain, E. Niggli, et al., *Die Mineralfunde de Schweiz*. Basel, Wepf, 1973.
2006 Philippe Roth., *Minerals first discovered in Switzerland and minerals named after Swiss individuals*. Achberg, Kristallografik Verlag, 2006. 239 p., illus. ["A brief history of mineralogy in Switzerland" can be found on pages 8 to 16, as well as much biographical information in the text proper.].

Alps

1917 Johann Georg Koenigsberger., *Ueber alpine Mineral-lagerstätten*. München, Verlag der Königlich Bayerischen Akademie der Wissenschaften; in Kommission des G. Franz'schen Verlags, 1917-19. 3 vols. [Published as: *Abhandlungen der Bayerischen Akademie der Wissenschaften*, **28** (1917), no. 10, [1]-35 p., **28** (1918), no. 11, [1]-131 p., map and **28** (1919), no. 12, p. [1]-108. The work contains a useful section called "Alte Litteratur" in the third volume.].
1940 Paul Niggli., *Die Mineralien der Schweizeralpen*. Basel, B. Wepf & Co., 1940. 2 vols.
1954 Robert Lüling Parker., *Die Mineralfunde der Schweizer Alpen*. Mit einen Ubersichskarte der zentralalpinen Mineralfundgebeite. Herausgegeben unter Mitwirkung der Schweizerischen Geotechnischen Kommission. Basel, Wepf, 1954. vii, 311 p., 3 plates, illus., 3 folding maps.
1966 Hans Anton Stalder., *Mineralien aus den Schweizer Alpen*. Vevey, Lexi-Bildband Verlag,, 1966. 56 p., illus., color.
1966 Ferdinand Jakob and Hans A. Stalder., *Mineralien aus den Schweizer Alpen*. 31 Farbphotos. [Vevey] Lexi-Bildband [c1966]. 56 p., colored illus., map.
1972 Johann Georg Koenigsberger and Paul Niggli., *Die zentralalpinen Minerallogerstätten*. Basel, Wepf & Co., 1972. [6], [311]-501, [629]-661 p., illus. [Reprint from the Teil III of *Die Mineralien der Schweizeralpen* (1940).].
1973 Hans Anton Stalder and F. Haverkamp., *Mineralien: Verborgene Schätze unserer Alpen*. Lausanne, Mondo Verlag, , 1973. 175 p., illus., color.
1974 P.F. Maissen., *Mineralklüfte und Strahler der Surselva*. Disentis, Desertina Verlag, 1974. 192 p., illus.

Binn Valley

1909 L. Desbuissons., *La Vallée de Binn: Etude Géographique, Géologique, Minéralogique et Pittoresque*. Lausanne, 1909. 336 p., illus., map.
1934 H. Bader., "Beitrag zur Kenntnis der Gesteine und Minerallagerstätten des Binnentals," *Schweizerische Mineralogische und Petrographische Mitteilungen*, **14** (1934), p. 319-441, map.
1978 Hans Anton Stalder, P. Embrey, S. Graeser and W. Nowacki., *Die Mineralien des Binntales*. Bern, Naturhist. Museum, 1978.
1980 E. Asselborn., "Minéraux de la vallée du Binn," *Monde et Minéraux*, **37** (1980), p. 10-13.
1994 A. Gorsatt., *Das Binntal und seine Mineralien*. Switzerland, Binn, 1994. 271 p., illus., color.

Gotthard Tunnel

1980 Hans Anton Stalder, Valentin Sicher and L. Lussmann., *Die Mineralien des Gotthardbahntunnels und des Gotthardstrassentunnels*. Gurtnellen [Switzerland], Repof AG, c1980. 160 p., illus. [Description of the minerals encountered while the Saint Gotthard Tunnel was excavated.].

Grimsel Region

1964 Hans Anton Stalder., "Petrographische und mineralogische Untersuchungen im Grimselgebiet," *Schweizerische Mineralogische Petrographische Mitteilungen*, **44** (1964), p. 187-398, illus.

Jura Region

1948 A. Frei., "Beitrag zur Mineralogie des Schweizer Juras," *Schweizerische Mineralogische und Petrographische Mitteilungen*, **28** (1948), p. 103-113.

### 11.2.3.3 Italy (Italia)[1160]

**REWORK:** Under the Roman Empire, the mineralogy of Italy had been covered in the ancient period by Pliny (see §———-). Little more in Italian mineralogy occurred until the Renaissance of the fifteenth century. All natural science, including studies of minerals, were investigated with the introduction of the printing industry at the mid point of the century. Medical books such as the herbals became very popular books as did commentaries on the ancient authorities. The Venetian Ermolao Barbaro wrote his *Castigationes Plinianae* as a positive

[1160] Further historical information may be found in: W. G. E. Caldwell and Gian Battista Vai, eds., *The origins of geology in Italy*. Special Paper 411. Boulder, Colorado, The Geological Society of America, 2006. xi, 223 p. [ISBN 0813724112.] • Guido Carobbi., "Il contributo Italiano al progresso della mineralogia, negli ultimi cento anni," *Un Secolo di Progresso Scientifico Italiano, 1839-1938*, **2** (1939), p. 429-451. • Reinhard Exel., *Sardinien: Geologie, Mineralogie, Lagerstätten, Bergbau*. Sammlung Geologischer Führer, 1986. 177 p., illus. [Contains a five page historical section beginning at page six.] • C. Gemmellaro., "Sommi capi di una storia della Geologia sino a tutto il secolo XVIII pe' quali si detegge che le vere basi di questa scienza sono state fondate dagli italiani," *Atti dell'Accademia Gioenia di Scienze Naturali*, **18** (1862), 40 p. • Michele Gortani., "Italian pioneers in geology and mineralogy," *Journal of World History*, **7** (1963), p. 503-519. • L. Pilla., "Cenno storico sui progressi della Orittognosia e della Geognosia in Italia," *Il Progresso della Scienze delle Lettere e delle Arti*, **2** (1832), pp. 37-81, **3** (1832), pp. 165-234 & **5** (1833), pp. 5-41. • F. Rodolico., "[History of Tuscan mineralogy]," *Rivista di Storia delle Scienze Mediche e Naturali*, **44** (1953), no. 2, p. 187-93. • Gian Battista Vai and W.G.E. Caldwell., *The origins of geology in Italy*. Boulder, Colo., Geological Society of America, 2006. xi, 223 p., illus. [Published as: *Special papers (Geological Society of America)*, no. 411.] • E. Vaccari., "Mineralogy and mining in Italy between eighteenth and nineteenth centuries: the extent of Wernerian influences from Turin to Naples" (pp. 107-130), in: Fritscher, B. and F. Henderson, eds., *Toward a history of mineralogy, petrology and geochemistry. Proceedings of the international symposium on the history of mineralogy, petrology, and geochemistry, Munich, March 8-9, 1996*. Münich, Institut für Geschichte der Naturwissenschaften, 1998.

commentary on Pliny's *Naturalis Historiae*. First published in Rome in 1492, it became a popular work, reprinted many times. Its review of Pliny's books 33-37 that treated mineralogical subjects is the beginning of modern Italian mineralogy.

### Sixteenth Century

The age when mineral science was first addressed in Italy, however, was the 16th century, when authors addressed mineralogical subjects in depth. The famous Camillo Leonardi was the earliest among these, publish his *Speculum Lapidum* (Speculation on Stones) in 1502. There Leonhardi applies scientific principles to his mineralogical classification, basing his divisions of the precious stones on their colors. Gabriel Fallopi in his *De Metallis atque Fossilibus* published in 1564 describes minerals and therapeutic waters. The work was published after Falloppi's death and is based on lectures he delivered on mineralogical subjects he presented at the University of ————.

In his *De Subtiliantum* of 1550 and *De Rerum Varitate* of 1557, Cardano repeats many of the superstitions of the past while discussing the uses to which minerals and especially gems may be put. Della Porta includes descriptions of minerals and fossils in his *De Miraculis Rerum Naturalium* published in Naples in 1589. The sixteenth century saw the first appearance of Biringuccio's *Pirotechnia* that although more properly a work on metallurgy contains much valuable information on the assaying and refining of minerals. Andreas Caesalpino devised a clever system of mineral classification that he presents in his *De Metallis* of 1596. The natural history of Egypt was treated by Alpino Prospero, but not published until 1735 long after his death. Another work compiled in Italy during the sixteenth century, but not published for centuries was Mercati's *Metallothean Vaticana* that described the native metals and related minerals contained in the Vatican collections of the time. In 1587, Andreas Bacci published his *Le XII Pietre Prezione* that is one of the first published commentaries on the identity of the twelve stone's contained in the high priest's breast plate. At the end of the century, Ferrante Imperato published his *Dell'Istoria Naturale* in 1599 that fully described the natural history cabinet he collected. It includes an interesting classification of the minerals.

### Seventeenth Century

Italy of the seventeenth century continued to see the appearance of books on mineralogical topics. In 1610 Francisco Imperato published his *De Fossilibus Opusculum* that gave further descriptions of the minerals and fossils contained in the natural history cabinet of his relative. Ulisse Aldrovandi was fascinated with all aspects of natural history and based his own extensive collection in that area. He authored 24(?) large books on various aspects of the study, of which his *Museaum Metallicum* of 1648 treats minerals, metals, and fossils. Brembati published his *La Mineralogia* (1663) that divides the subject into four books, that provide in-depth discussions of locating mineralized veins in caves and mines, how to extract the mineralized ore, and reduce the ore to a perfect metal.

Baglivi wrote his *De Vegetatione Lapidium* published in 1730 that assigns the formation of minerals and stones to a process similar to the growth of vegetables. Arnobio wrote a work on precious stones, *Tesoro Delle Gioie* (1602).[1161] A dissertation on asbestos was published in 1691 by Ciampini.[1162]

The phosphorescent barite found in Bologna was the subject of much speculation by Fortunio Liceti (1640),[1163] Marco Antonio Cellio (1681),[1164] and Conte Luigi Ferdinando Marsigili (1698).[1165]

In the Seventeenth century, the celebrated mathematician Domenico Guglielmi published his ingenious ideas on crystallography in 1688 that described the various geometrical forms made by the crystals of various salts. This work added greatly to descriptive crystallography. It was followed in 1705 by his disser-

[1161] ???

[1162] ???

[1163] *Litheosphorvs, Sive De Lapide Bononiensi.*

[1164] *Il Fosforo o Vero la Pietra Bolognese.*

[1165] *Del Fosforo Minerale.*

tation on salts, a work much less well known. Here he extends his original ideas by developing them mathematically based on his observations of the physical crystals. He distinguished secondary forms of the basic geometric shapes and speaks of the constant shape of the crystal forms among the same species. In this work, Gugliemini also appears to anticipate the theories of Bergman and Haüy by recognizing that there is a tiny crystal molecule that formed the nucleus inside the crystal.

**Eighteenth Century**

Italian mineralogy was extended by the illustrious mineralogist and geologist Giovanni Arduno who investigated the minerals, fossils and mines of the peninsula. A large number of his mineralogical writings were collected together and published in 1775.[1166] Still others were published in the *Memoirs* of the Italian scientific societies.[1167] For his work, Arduniono justifiably gathered an expert reputation through out not only Italy, but the rest of Europe.

A near contemporary of Ardunio was the celebrated Giovanni Scopoli. His first work dealt with the health of the miners of Indria, who became poisoned from the mercury they mined. He became an instructor in chemistry at the mining school of Schmenitz. He also studied the crystals of Hungary,[1168] and compiled a treatise on mineralogy,[1169] and supplied numerous mineralogical notes to Macquer's *Dizionario Di Chimie* that he translated into Italian.[1170]

The writer and scientist Ermenegildo Pini was important to the mineralogy of eighteenth century Italy. He discovered many new minerals, especially on specimens he recovered from Mount Tremola, St. Gottardo. He described tremolite, and was the first to recognize adularia as a variety of feldspar, that was named after the ancient name of St. Gottardo. He studied the minerals of the iron mines located on the island of Elba,[1171] and in the process developed new methods to extract the metals and provide better refining procedures.

Giuseppe Baldassari a naturalist of Tuscany in 1750 authored his *Osservazioni Sopra il Sale della Creta* that gave a full description of the natural history of Siena, Italy, including accounts of the geology and mineralogy of the region. A second part gives a catalog of the natural history specimens collected in the area.

The mineralogy of the area of Piemont was first described in the 18th century. Carlo Antonio Galeani Napione, on of the German trained mineralogists who returned to their native land, investigated minerals of the region with more accuracy than had previously been done. The mineral and mining resources of the mountainous regions of the Cavavois,[1172] the rhodochrosite of the Piemonte was described,[1173] which had first been discovered at Kapnik, Hungary, as was a chemical examination of Piemonte marbles,[1174] combinations of iron with sulfur, and published a textbook of mineralogy based on Wernerian principles that was highly regarded.[1175]

De Robiliant was sent by the King of Sardinia to study at Freiberg, to better learn the latest metallurgical techniques. He made an extensive tour of the European mining regions, before focusing his attention on the mineral resources of the Piemont. He applied much zeal in his investigations writing a topographical study of the areas mineralogical products.[1176] He also did considerable experimentation on platinum.[1177]

Bonvoisin also did mineralogical research in the Piedmont, describing hydrophane,[1178]

[1166] ???
[1167] p. 46-47.
[1168] ???
[1169] ???
[1170] ???
[1171] ???
[1172] ???
[1173] ???
[1174] ???
[1175] ???
[1176] ???
[1177] ???
[1178] ???

turquoise,[1179] diopside,[1180] and topaz[1181] of the region. He discovered a deposit of lead in the state of stura and the Po, and published a monograph on crystallized titanium oxide (titanite) found near the village of St. Martino in the Alps.[1182]

The minerals of the Bergamo mountains were described by Mairone da Ponte, who wrote a natural history of the region,[1183] a separate paper on the minerals and ores mined in Bergamo,[1184] and a chemical description of the iron carbonate ore (siderite?) mined at Serio.[1185]

Angelo Gualandris after having traveled through out a large part of Europe to learn techniques of mineral and metal work, returned to Italy, and introduced improvements to the mining and metallurgical processes that he recorded in his *Lettere Odoporiche* of 1780.

Serafino Volta published in 1787 his *Elementi di Mineralogia*, a textbook based on Werner's theories that was held in great esteem, and contained the author's innovative thoughts on the formation of minerals, comparing the role of crystallization with that of organization of the chemical molecules.[1186] He was also occupied with the examination of crystallized minerals from Hungary,[1187] and cataloging the mineral specimens of a private collection in Pavia, known under the name Museo Bellisomiano.[1188]

Giuseppe Benvenuti compiled a treatise on mineralogy, *Istituzioni di Mineralogia* that was published in 1790, and contained descriptions of many Italian minerals.

Leopoldo Fabbroni demonstrated that the ancient gem Pliny called 'obsidian' that was said to be found at Ossidio in Ethiopia, was the same stone as the obsidian glass found near the Italian volcanoes.[1189] He also translated from the German, Wilhelm August Lampidius's guide to mineral analysis, which was published in 1803 as *Metodo Pratico per Analizzare i Minerali*.

The mineral product alum, which Italy had mined since ancient times, was the subject of investigation. The early work of the illustrious geologist Scipion Breislak gave a comprehensive study of the mineral recovered at Tolfa, including its chemical analysis, how it was mined, how to determine if a deposit is economic, and methods of preparation. Breislak also for many years studied the solfatare found at Pouzzuoli and used in the manufacture of a cement that would set even under water. He collected together his observations, including a mineralogical examination and published the book in 1792.[1190] He went on to the broader study of geology making a large impact in that discipline.

In the Memoirs of Cremelli, the mines and their various metals and minerals are described.[1191]

In 1792, Giovanni Vincenzo Petrini published a detailed description of the mineralogical collection at the Nazareno College in Rome, which was the most extensive collection at the time in the city. As an instructor in Natural History at the College, he wrote a course book that dealt in part with mineralogical subjects.[1192]

Girmaldi published an account of the mines and mineral resources discovered during the rule of Carlo III.[1193] The were found in Calabria and Sicily. In 1788, Fasano gave a scholarly account of the metallic minerals and ores of Calabria that included information on the localities from which they came.[1194]

Candid in a letter addressed to the celebrated Vincenzo Petagna published information on the molybdenite found at Olivadi in

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[1180] ???
[1181] ???
[1182] ???
[1183] ???
[1184] ???
[1185] ???
[1186] ???
[1187] ???
[1188] ???
[1189] ???
[1190] ???
[1191] ???
[1192] ???
[1193] ???
[1194] ???

Cambria. He gives a chemical analysis of the mineral. [1195]

### Vesuvius

The ancient volcano of Vesuvius is a place to rich in mineral species to go unnoticed by Italian researchers. During the reign of Carlos III, the Abbé Ferdinando Galiani in 1772 published a catalog of minerals collected at Vesuvius.[1196] He presented a copy of his book and a collection of mineral specimens to Pope Benedict XIV. Sal Ammonico found at Vesuvius was the subject of observations by De Tommasi.[1197] But the first scientific examination of Vesuvius' minerals was conducted by Gioeni, who used the authorities of Wallerius, Cronstedt, and Bergman to described all the known mineral species of the volcano.[1198] It was the model on which all later mineralogists would assemble their studies of volcanic mineralogy.

### Nineteenth Century

Advances in European mineralogy of the nineteenth century carried through to Italy. Abbé Gismondi discovered a new mineral that he named Haüyne in honor of the great French mineralogist. A complete description of the mineral was read by Gismondi before the Accademia del Lincei in Rome in 1803.[1199] He became professor of mineralogy at the University of Rome, and in that capacity mad a study of Italian minerals discovering abrazite. The mineral gismondinite was named in his honor by Leonhard. He described some new minerals found around Rome.[1200]

Bossi published on the idrofane stone,[1201] and preformed in 1807 a mineralogical analysis of an ancient vase.[1202]

The mineralogical museum at Pavia was enriched under the curatorship of Giovanni Martinenghi, who compiled a catalog of the collection in 1801, *Distribuzione Ragionata del Museo Mineralogico dell' Univerisita' di Pavia*, followed by a supplement in 1802.

Giorgio Santi wrote about a tour through Tuscany he made and published an account in 1806, *Viaggio al Montamiata*. It included observations on the natural history, and includes descriptions of the minerals of the region, including localities, and describes tourmaline, maganite, and anthracite. In 1802, Spadoni gave mineralogical observations of the area near the ancient village of Lasio, noticing the metals and bitumens.[1203]

Viviani who had studied botany wanted to extend his researches into the mineral kingdom. He described a new titanium iron oxide (menakanite),[1204] and gave a full account of the new mineral ligurite.[1205] Moion made a chemical examination of ligurite.

Giovanni Battista Brocchi was famous as a mineralogist and geologist of the period. He made many important studies. [**LOOK UP IN DSB**].

The work of Conte da Río concentrated on the minerals and fossils of Padovano and Vicentino on which he wrote with distinction. He gave observations on the mine of Agordo and other localities in the Bellunese territory,[1206] on pearlite found in the Euganei Mountains,[1207] a description of a mineral presented as a gift to ————,[1208] and of materials used at the pottery factory at Brenta.[1209]

Conte Marco Coriani wrote on metallurgy, fossils, and minerals.[1210]

Stefano Andrea Renier compiled an elementary treatise on mineralogy, *Elementi di Mineralogia* (1825), in which he planned to describe all the objects of the science. He died before the work was complete and

[1195] ???
[1196] Catalogo delle Materie appartenenti al Vesuvio
[1197] ???
[1198] ???
[1199] ???
[1200] ???
[1201] ???
[1202] ???
[1203] ???
[1204] ???
[1205] ???
[1206] ???
[1207] ???
[1208] ???
[1209] ???
[1210] p. 63

his widow published the second volume that dealt primarily with fossils. His *Cenni Storici sulla Mineralogia in Generale* (1823) was the first volume in a proposed series to give a full description of the science, with special emphasis on Italian mineralogy, but again Renier died too soon to complete the project.

Tommaso Antonio Catullo [1782-1869] was one of the greatest mineralogists of the 19th century. Trained in the medical profession, Catullo was appointed in 1811 an instructor of natural history and chemistry at Belluno, followed in 1815 at Verona and in 1822 at Venice. Soon thereafter, he was appointed a professor in the same subjects at the University of Padua. He held membership in the Società Italiana. In 1812, he published his *Manuale Mineralogico* (Mineralogical Manual), which contained many descriptions of Italian minerals. In a letter to Breislak, he described some minerals common to Agordo and adjacent regions.[1211]

Conte Marzari Pencati wrote about his discovery of strontanite ($SrSO_4$).[1212] One curious aspect was that some of the specimens were in the exact shape of shells.

Rosina scholarly dealt with some minerals found in Ossola, which was rich in such things and at the same time indicated means to generate greater profit from the mines.[1213]

Minerals found in Catria were the subject of a paper by Bellenghi.[1214]

The green earth of Verona, described first in the *Metallotheca Vaticana* and later by Bromell and Wallerius, to whom the first modern description is attributed. Brignoli provides a complete and scholarly description, following the methods of Haüy and Bronignart.

The mineral species found on the Isle of Elba were the subject of much investigation by many scholars. Targioni-Tozzetti described the species foun there in 1825.[1215] Carpi, a student and successor of Gismondi in the chair of mineralogy also wrote on the islands minerals in 1827.[1216] Carpi also described minerals found near Rome.[1217]

The island of Sardina did not escape notice. Tonelli wrote on a variety of minerals described on the island.

In 1789, in an attempt to train technicians capable of exploiting and deriving value from the mineral resources of the Kingdom of Naples, Ferdinand IV and his wife Maria Carolina had the innovative and far-sighted idea of organizing a competition for students in mineralogy. The winners were to attend European mining and mineralogical schools and to visit mines and metallurgical plants. The aim was to acquire as much technical information as possible for the planned reorganization and exploitation of mines in southern Italy, but was also to create a new specialized staff of mining experts. The winners were Giovanni Faicchio, Carmine Antonio Lippi, Giuseppe Melograni, Vincenzo Ramondini, Andrea Savarese and Matteo Tondi.

These erudite young men left in May 1789 on their sojourn. First they traveled to Schemnitz, where they were taught the latest theories and technologies. At the end of 1792, they traveled to Saxony, where from 1793 to 1795 they attended the Freiberg Bergakademie, where Werner was the most prominent teacher, and he profoundly influenced the young Italians, converting them to his theories. At the conclusion of their education, the group made an extensive tour of the mining districts of Hungary, Saxony, Bohemia, Gallica, Poland, Holland, England, Scotland and Ireland, reviewing the mines, minerals, iron and steel works, as well as the mineralogical cabinets. Along the way they cultivated friendships with the leading naturalists and mineralogists of the time. After seven years and three months this band of newly trained mineralogists returned to Italy, burdened down with specimens, models, books, apparatus, and the like, that was lacking from the Italian mineralogical institutes. Soon they took up positions of importance in state mining operations.

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Giovanni Faicchio, having contracted some form of serious disease during his return trip, died soon after returning home.

Andrea Savarese [1762-1809] during his training in Scheminitz became an expert in the chemical analysis of minerals, and after his return communicated his findings to the leading chemists of the time including Klaproth, Fourcroy, Westrumb, Crell, and von Born. These chemists occassionly made honorable mention of his work in their publications. Savarese also published a number of papers in the Italian journals of the day. Savaresi became a prominent mining expert and officer.[1218]

Vincenzo Ramondini [1758-1811] became Director of the Mineralogical Museum established in Naples in 1801 and arranged according to the Wernerian system: this museum, based on the geo-mineralogical specimens collected and classified by Tondi and Lippi during their European travels, was one of the richest of its time.[1219]

Giuseppe Melograni [1750-1827] became vice-director of the Mineralogical Museum established in Naples, helping Ramondini.

Carmine Antonio Lippi [1761-1823] like the majority of the Neapolitan mineralogists, apart from Tondi, concentrated on the study of Vesuvius. In an interesting letter sent to Werner in 1815, Lippi revealed to the master his intention to publish a book for demonstrating that Pompei and Ercolano "were buried by the floods, which formed the over lying mountains, but not because of Vesuvius". According to Lippi, these floods ('inondazioni' or 'alluvioni'), not connected with the activity of the volcano, happened subsequently in different ages and deposited a regular series of strata over the two ancient towns. This new and provoking interpretation caused several negative reactions in Naples when Lippi published his book in 1816. It was dedicated to Werner and had the title *Fu il fuoco o l'acqua che sotterrò Pompei e Ercolano?*, that is to say, "Was it fire or water which buried Pompei and Ercolano?".

Matteo Tondi [1762-1835] graduated with a medical degree from the University of Naples where, he had also followed studies of botany, physics and chemistry. During his travels through the European mining districts, Tondi collected specimens, with passion and competence, assembelling approximately 35 mineral cases that were sent to Naples for incorporation into the Mineralogico Museum. In 1799, due to political reasons, he relocated to Paris, where he was added to the chair of Mineralogy in the Natural History Museum of Paris, directed at the time by the celebrated Dolomieu. In Paris, he became closely associated with Haüy who he greatly admired. The esteem was reciprocal, since Haüy entrusted the collection of specimens for his research to Tondi. Haüy showed his gratefulness to Tondi by presenting him with a silver cup bearing the inscription: 'Matteo Tondi A Crystallographo Haüy in amicitiae tesseram'. In 1811, Tondi returned to Naples and was appointed Inspector General of Rivers and Forests. In 1815, by virtue of his scientific fame, he was nominated to fill the vacancy at the chair of Oryctology at the Royal University, and the direction of the Royal Mineralogical Museum.

In 1806, Tondi was nominated professor of mineralogy at the University of Naples (a newly established chair), but he preferred to remain for some other years in Paris where he was working with Rene Just Haüy at the Museum d'Histotre Naturelle. Consequently Ramondini held the chair of mineralogy until 1811, the year of his death, when Tondi carne back from Paris to take up in 1815 the position which would later become the chair of mineralogy and geognosy. Matteo Tondi was certainly the most distinguished of the Neapolitan mineralogists of the early nineteenth century. His scientific training, started in Schemnitz and Freiberg, was completed in Paris, but the influence of Werner on his geological ideas, as in the case of Lippi and Melograni, was definitely predominant. After his return to Naples, Tondi dedicated his time to preparing a Wernerian treatise of 'geognosy' which he also intended to be a complete geo-mineralogical nomenclature

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[1219] A. Scherillo., "La storia del 'Real Museo Mineralogico' di Napoli nella storia napoletana," *Atti dell'Accademia Pontantana*, New Series, **15** (1965-6), p. 3-47, plates I-XXI.

written in Italian. It was an ambitious project similar to the one attempted some years before by Napione, but Tondi managed to finish it: in 1817 he published the *Elementi di Onttognosia* and in 1824 the *Elementi di Oreognosia*.

The Royal Mineralogical Museum was inaugurated by Ferdinand IV, probably in 1801, and soon became an important centre of scientific research to cope with the demands of the country. Its scientific worth grew with time, and in 1845 the 7th Congress of the Italian Scientists was held at the Museum. The Royal Mineralogical Museum played a key role in important socio-political events: after Ferdinand II had granted the Constitution in 1848, the Chamber of Deputies held meetings in the 18th-century Hall. In 1861 the Hall was used as an electoral polling station in the vote for the annexation by the Kingdom of Italy.

Francesco Ferrara [1767-1850] was intended for a career with the church, but became interested in science after witnessing an eruption of Etna. Afterwards he focused his attention natural history, graduating from the University of Catania in 1786 with degrees in medicine and philosophy. He corresponded with Dolomieu and Spallanzani. After graduation Ferrara continued his theological studies and was ordained a priest in 1792. In 1802 he was appointed professor of physics at the University of Catania. His *Storia naturale della Sicilia che comprende la Mineralogia* (1813) is one of many books dealing with the natural history of the island of Sicily. This particular title deals principally with the mineralogy of the island.

Abate Teodoro Celestino Monticello [1759-1846], a Benedictine monk, was from 1792-4 professor of ethics at the University of Naples. He then accepted a political position until 1800. From 1808, he was professor of chemistry at the University of Naples. Monticelli was a member and standing secretary of the Academy of Science of Naples. His studies were of the geology and minerals of Vesuvius and the Phlegraen Fields. His collections were acquired by the Real Museo Mineralogico in Naples.

Niccola Covelli [1790-1829] was a professor of chemistry at the University of Naples, as well as a member of the city's academy of science.

The *Prodromo della Mineralogia Vesuviana* (1825) was co-authored by Monticelli and Covelli who both frequently traversed the slopes of Vesuvius, examining the volcanic ejecta and formations. This book is the first portion of a work to describe the whole of their discoveries. Although this is the only portion to appear, it is a remarkably comprehensive and detailed examination of the minerals found in and around Vesuvius. No more volumes were published, although an appendix appeared in 1839.

In Italy the modern mineralogical research begins only around 1840 with the work of Arcangelo Scacchi [1810-1893], who exercised a tremenous influence in his own country. He was rigorous in his crystallographic descriptions. Using a reflecting goniometer, he deduced that the polyhedra faces of the cystals obeyed precise laws in their formation. In fact he established himself as a crystallographer by confirming the celebrated researches of Louis Pasteur [1822-1895], who developed the idea that the enantiomorphism of some crystals is tied to the asymmetry of the molecule, which is so important to stereochemistry. When Scacchi was appointed Director in 1842, the Royal Mineralogical Museum acquired a significant role in the scientific community. In fact, this eminent scientist gave a considerable impulse to regional mineralogical research, particularly in the Vesuvius area. One of the first steps taken by Scacchi was to purchase the collection assembled by Teodoro Monticelli, who had started studying Vesuvian mineralogy on a scientific basis. At present, this collection is part of the Vesuvius Collection, the only one of its kind in the world. In 1862 Scacchi had the museum renovated, personally selecting the crimson and green tiles from Colonnese's works in Naples. They still line the floor of the 17th-century Hall. His son, Eugenio Scacchi [1854-1929] was also a mineralogist and vulcanologist who taught at the University of Naples (1880-1890), Genoa (1890-1891), returning to Naples thereafter. He wrote on Vesuvian and other Italian minerals.

Quintino Sella [1827-1884], an Italian

patriot and statesman as well as mineralogist and crystallographer, worked between 1856 to 1861 on Italian minerals from many localities.[1220]

Johannes Karl Theodor Strüver (called Giovanni Struever) [1842-1915], a German mineralogist, migrated to Italy in 1868. Between 1868 and 1873 he was professor of mineralogy and geology at the University of Turin, and from 1873 he was profess of mineralogy at the University of Rome, developing an important department of mineralogy and crystallography. He authored many papers on the mineralogy of Italy.

Antonio d'Achiardi [1839-1902] researched the minerals of Tuscany, and wrote many papers on the subject.

Giovanni d'Achiardi [1872-1944]

Luigi Bombicci Porta [1833-1903] was a geologist and mineralogist.

Ruggero Panebianco [1848-1930] was a crystallographer who taught at the University of Padua from 1883 to 1923. He studied principally the morphological aspects of crystals. He worked on the helicodal crystallization of quartz and other compounds, and contributed much to the development of these studies. He showed the isomorphism of the dioxide of molybdenum ($MoO_2$).[1221]

Carlo Maria Viola [1855-1925] studied the physical properties of minerals, including the determination of refractive indexes.

Luigi Brugnatelli [1859-1928] a mineralogist and crystallographer from 1888 taught at the University of Pavia. He described the new species artinite, and the mineral brugnatellite was named in his honor.[1222]

The famous Italian mineralogist and vulcanologist Ferruccio Zambonini [1880-1932] in 1912 published his "La Mineralogia In Italia Negli Ultimi Cinquant'anni"[1223] and his famous *Mineralogia Vesuviana* (1910), which is an outstanding topographical mineralogy, giving in this edition and the expanded second edition (publ. 1934), the best description of the various mineral species found at Mount Vesuvius in Italy. The text gives an overview of the volcano, its history and its geology, followed by a detailed descriptive list of minerals found on its slopes. To verify identification, Zambonini preformed chemical analysis in his descriptions.[1224]

Ettore Onorato [ - ] Italian mineralogist. [1225]

E. Montanaro Gallitelli [ - ] Italian mineralogist. [1226]

Fenoglio[1227]

Scherillo

Bonatti[1228]

Sanero[1229]

Gattitelli[1230]

William Puget Jervis [1831-1906], an English mineralogist and museum specialist worked in Italy from 1850 forward. He authored many papers on the minerals of Tuscany and other regions of Italy, compiling a list of mineral sources of Italy in his exhaustive *I tesori sotterranei dell'Italia* (Torino, 1873-1889).

Piero Aloisi [1881-1938] taught at the University of Firenze (from 1924), and studied minerals and rocks from Italy, Abyssinia, the Himalayas and Turkestan.[1231]

Ettore Artini [1866-1928] worked at the University of Milan. He worked on the minerals of Italy and described three new species. The mineral artinite was named in his honor.[1232]

Grattarola[1233]

Another worker on Italian mineralogy was Federico Millosevich [1875-1942] who taught mineralogy and crystallography at the University of Rome. He was especially

[1220] Carobbi, p. 434-435.

[1221] Carobbi, p. 441.

[1222] Carobbi, p. 437 & 449.

[1223] F. Zambonini., "La Mineralogia in Italia negli ultimi cinquanta anni," *Atti Della Societa' Italiana Per Il Progresso Delle Scienze*, **??** (1912), p. ??-?? (40 p.).

[1224] Carobbi, p. 440-442.

[1225] Carobbi, p. 436.

[1226] Carobbi, p. 437.

[1227] Carobbi, p. 437.

[1228] Carobbi, p. 437.

[1229] Carobbi, p. 438.

[1230] Carobbi, p. 446.

[1231] Carobbi, p. 439 & 446.

[1232] Carobbi, p. 445.

[1233] Carobbi, p. 446.

interested in the mineral species of Sardinia. He founded the *Periodico di Mineralogia* that spread the work of Italian mineralogist to their countrymen and the rest of the scientific world. The mineral millosevichite was named in his honor.

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1880 W.S. von Waltershausen., "Die Mineralien des Aetna," *Der Aetna*, Leipzig, **2** (1880), p. 485-530.

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Lombardi

1970 M. Boscardin, V. de Michele, and G. Scaini., *Itinerari Mineralogici Detta Lombardia*. Milano, Museo Civico di Storia Naturale, 1970. 120 p., illus.

Malenco Region

19?? G. Guiscardi., *Guida ai Minerali detta Val Malenco*. 19—. 60 p., illus.

n.d. V.F. Bedogne, A. Montrasio, and E. Sciesa., *Val Malenco–Il Minerali detta Provincia di Sondrio*. Milano, n.d. 275 p., illus.

Ossola

1979 V. Mattioli., *Minerali Ossolani*. Milano, Semeriglio Rapazzini, 1979. 300 p., illus., color.

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1858 Q. Sella., "Studii sulla mineralogia Sarda," *Mémoire. Accademia Torino*, seria 2, **17** (1858), p. 289-336.

1925 E. Billows., *Lessico Mineralogico per L'Isola di Sardegna*. Second edition. Cagliari, 1925. 115 p.

1985 A. Pietracaprina and G. Brizzi., *La Sardegna ed i suoi Minerali*. Sassari, Editrice Mediterranea, 1985. 320 p., illus., color.

1986 Reinhard Exel., *Sardinien: Geologie, Mineralogie, Lagerstätten, Bergbau*. Sammlung Geologischer Führer, 1986. 177 p., illus. [Contains a five page historical section beginning on page six.].

1991 G. Conti-Vecchi and P. Stara., *Minerali Di Sardegna*. Cagliari, Edizioni Delia Torre, 1991. 240 p., illus.

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1898 G.B. Traverso., *Sarrabus e Suoi Minerali*. Alba, 1898. 73 p.

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1780 M.J. De Borch., *Mineralogie Sicilienne*. Turin, 1780. 342 p.

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1811 G.B. Brocchi., *Memoria Mineralogica sulla volle di Fassa in Tirolo*. Milano, 1811, 259 p.

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1984 K. Folie., *Die Mineralien Südtirols und des Trentino*. Mevan, Tappeiner, 1984. 220 p.

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1976 G. Carobbi and F. Rudolico., *I Minerali della Toscana*. Firenze, Leo Olschki, 1976.

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1910 F. Zambonini., "Mineralogia Vesuviana," *Atti Accad. Sci. Napoli*, ser. 2, **14** (1910), no. 6, 368 p. Supplement **15** (1912), no. 12, 51 p. 2nd edition 1935, edited by E. Quercigh, ser. 2, **20**, 463 p.

1982 M. Carati., *Guida alla Mineralogia Vesuviana*. Bologna, Edizioni Calderini, 1982. 121 p., illus., color.

## 11.2.4 Low Countries[1234]

### 11.2.4.1 Belgium[1235]

[1234] Further historical information may be found in: W. Schmidle., "Die Geschichte der geologischen Erforschung des Bodensees," *Badische Geol. Abhandlung*, **3** (1931), p. 1-40, 81-95, 6 illus. • Paul Siegfried., "Die geologische Erforschung der Baltischen Lander," *Geologische Rundschau*, **31** (1940), Heft 7/8, p. 488-494, portrait. [Outline of the history of geological research in the Baltic region. The contribution of Friedrech Schmidt [1832-1908] are especially noted.]

[1235] Further historical information may be found in: Marcel Denayer., "Les sciences minérales en Belgique de 1830 á 1930" (pp. 248-251) in: *Livre d'or du Centenaire de l'Indépendance Belge*. Bruxelles/Anvers, Leclercq, De Ridder et De Haas, 1931. • Gustave Dewalque., "Coup d'oeil sur la marche des sciences minérales en Belgique,"

Topographical Studies

1803 A. Rozin., *Essai sur l'étude de la minéralogie*. Avec application particulière au sol Français, et surtout à celui de la Belgique. Bruxelles, De limprimerie de Tutot; Paris, Chez Fuchs, [1803?]. [8], 332, xxxvi p. [An early study in the topographical mineralogy of France and Belgium.].

1913 C. Malaise., "Les espèces minérales do Congo Belge" (pp. 577-597) in C. Malaise., *Manuel de Mineralogie*, 4th edition, Bruxelles, 1913.

1947 Henri Buttgenbach., *Les Minéraux de Belgique et du Congo Belge*. Paris, Dunod, 1947. xvii, 573 p., 17 plates, diagrams, folding map. [Topographical mineralogy of Belgium and its colony, now called the Congo Democratic Republic).].

## 11.2.4.1 Luxemburg (Luxembourg)[1236]

Topographical Studies

1864 C. Clement., *Apercu général de la constitution géologique et de la Richesse Minérale du Luxembourg*. Luxembourg, 1864. 147 p.

## 11.2.4.1 The Netherlands (Holland)[1237]

Topographical Studies

1923 H. Keienboek and P. Van der Lijn., *Mineralien, Gesteenten en Fossielen in Nederland*. Zutphen, Thieme, 1923. [Revised 1960s.].

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1963 P. Van der Lijn., *Het Keienboek. Mineralen, Gesteenten en Fossilen in Nederland*. 5. Auflage. Amsterdam, 1963. 390 p., 354 illus.

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Topographical Studies

1983 E. Pumo., "Geologie und nutzbare Mineralien Albaniens," *Österreichische Osthefte*, **25** (1983), p. 26-55, illus.

## 11.2.6.1 Armenia[1238]

Topographical Studies

1920 Hagop A. Karajian., *Mineral resources of Armenia and Anatolia*. New York, Armen Technical Book Co., 1920. 211 p., illus., maps, biblio. [Describes the mines and mineral resouces of the Republic of Armenia and Anatolia of Turkey.].

1936 Nikolai Mikhailovich Fedorovskii., *Ekonomicheskaia mineralogiia SSSR*. Moskva, Izd-vo Akademii nauk SSSR, 1936. 244 p., illus., maps, biblio. [Describes the mines and mineral resources of Armenia (Republic).].

1974 Shavarsh Oganesovich Amirian and Andranik Semenovich Faramazian., *Mineralogiia, geokhimiia i usloviia obrazovaniia rudnykh mestorozhdenii Armianskoi SSR*. Erevan, Izd-vo AN ArmSSR, 1974. 252, [4] p., illus. [Mineralogy, geochemistry and ore deposits of the Republic of Armenia.].

## 11.2.6.1 Belarus[1239]

Topographical Studies

1991 Nikolai Dmitrievich Mikhailov., *Rudnye mineral'nye assotsiatsii devonskikh otlozhenii Belorussii*. Minsk, "Navuka i tekhnika", 1991. 122 p., [52] p. of plates, maps. [Mineralogy and ore deposits of Belarus.].

## 11.2.6.1 Bulgaria (България)[1240]

*Bulletin de l'Academie royale de Belgique, 2* me *série*, **30** (1870), no. 12, p. 1-42. • *ibid.*, "Mineralogie", in: Adolphe Quetelet, et al., *Histoire des Sciences, Des Lettres et des Beaux-Arts en Belgique. Travaux de L'Académie Royale de Belgique (1772-1872)*. Bruxelles, Mucquardt, 1879. 2 vols. [Published on the occasion of the 100th anniversary of the Royal Belgian Academy. This publication comprises lenghty sections written by authorities on the history of science and art in Belgium during the period 1772-1872.]

[1236] Further historical information may be found in: Michel Lucius., *Beiträge zur Geologie von Luxemburg*. Publications du service geologique de Luxembourg. Zweite, umgearbeitete Auflage. Luxemburg, Mertens, 1955. 2 vols. [Contains in volume two on pages 1-289 a history and bibliography of geological research in Luxembourg.] • *ibid.*, "Aperçu historique sur les recherches géologiques concernant le Pays de Luxembourg," *Société des Naturalistes Luxembourgeois. Bulletin*, **51** (1959), p. 130-141. • Adolph Sprunk., "L'exploration du sous-sol du Grand-Duché de Luxembourg sous le régime hollandais," *Institut grand-ducal de Luxembourg. Section des sciences naturelles, physiques et mathématiques, Archives*, n.s., **19** (1950), p. 165-180. [Summarizes data on the early history of mineral exploration in Luxembourg, with special reference to activities under the Dutch regime, 1815-1830.]

[1237] Further historical information may be found in: L. Beek., *Dutch pioneers of science*. Assen, The Netherlands, Van Gorcum, 1985. 181 p., illus. [ISBN 9023221397.] • W. Schmidle., "Die Geschichte der geologischen Erforschung des Bodensees," *Badische Geologische Abhandlung*, **3** (1931), p. 1-40, 81-95, 6 illus. • R. Visser, ed., *Dutch Pioneers in Earth Sciences*. Edison, Editorial Indo America, 2004. [ISBN 9069843897]

[1238] Further historical information may be found in: K.A. Mkrtčjan and S.E. Goginsjan., "Die grundlegenden Etappen und Richtungen des Berg- und Hüttenwesens in Armenien," *Geologie. Zeitschrift für das Gesamtgebiet der Geologischen Wissenschaften*, **20** (1971), Heft 4/5, p. 522-528. [Main stages and trends in the mining and metallurgical industries of Armenia.] • S.S. Mkrtchian, K.N. Paffengolts, and E.G. Malkhassian., "The evolution of geological notions in Armenia," (pp. 244-260) in: V.V. Tikhomirov, ed., *History of Geology*. Yerevan, Izd. Akademii Nauk Armianskoi SSR, 1970.

[1239] Further historical information may be found in: Konstantin Ignat'evich Lukashev., *Istoriia geologicheskikh nauk v Belorusskoi SSR*. Minsk, Nauka i Tekhnika, 1978. 271 p. [History of geological sciences in Byelorussian SSR.]

[1240] Further historical information may be found in: Paul T. Craddock., *Early metal mining and production*. Edinburgh, Edinburgh University Press, c1995. xix, 363 p., illus. [Early history of metallurgy and ore deposits, including references to minerals mined.; ISBN 0748604987.] • G.K. Georgiev., "Bemerkungen zur Entwicklung der Kentnisse über die nutzbaren Bodenschätze in Bulgariaen vor seiner Befreiung von der Türkenherrschaft (im Jahre

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1923 Georgi Bonchev., "Минералите в България" [Minerals in Bulgaria], *God. Sof. univ., Fiz.-mam. fak.*, **19** (1923), no. 1, p. 1-212.

1964 Ivan Kostov, V. Breskovska, J. Mincheva-Stefanova, and G.N. Kirov., *Mineralite v Bulgariia.* Sofia, Izdatelstvo Bulgarskata Akademiya Naukite, 1964. 540 p. [Topographical mineralogy of Bulgaria, that contains a short history of the science in the country and a long bibliography on pages 518-532.].

1978 Khristo Spasov., *Bibliografiiă na literaturata po geologiiă na Bulgariiă 1828-1964.* Sofiiă, Izd-vo na Bulgarskata akademiiă na naukite, 1978. 512 p. [Bibliography of geology publications in Bulgaria.].

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## 11.2.6.1 Estonia[1241]

Topographical Studies

1991 Eesti Geoloogide Ülemaailmne Kokkutulek., *Eesti geoloogiline ehitus ja maavarad sümpoosiumi materjalid.* Tallinn, Eesti Geoloogia Selts, 1991. 100 p., illus., maps. [Geology and mineral resources of Estonia, a congress of papers.].

1997 Anto Raukas, et al., *Geology and mineral resources of Estonia.* Tallinn [Estonia], Estonian Academy Publishers, 1997. 436 p., illus., maps.

## 11.2.6.1 Latvia (Latvija)[1242]

## 11.2.6.1 Lithuania (Lietuva)[1243]

Topographical Studies

1994 Algimantas Grigelis and Rimantas Gailius., *Lietuvos geologija monografija.* Vil'nius, Mokslo ir Enciklopediju Leidykla Geologijos Institutas, 1994. 447 p., illus., maps. [Geology and mineral resources of Lithuania.].

## 11.2.6.1 Romania (România)[1244]

Topographical Studies

1897 Alphonse-Frédéric de Richard., *Richesses minérales de la Roumanie pétrole, eaux minérales.* Bucarest, 1897. [2], iv, 423, [1] p.

1900 P. Poni., "Etudes sur les minéraux de la Roumanie," *Ann. Sci. Univ. Jassy*, 1900, p. 15-148.

1925 D.M. Cadere., "Fapte Pentru a Servi la Descrierea Mineralogica a Romanâniei," *Mem. Sect. Sci. Acad. Româna*, series 3, **3** (1925-1928), no. 5, p. 1-43.

1878)," *Geologie*, **20** (1971), Heft 4/5, p. 529-541, 19 illus. [Notes on the development of Bulgaria's useful mineral resources before the liberation of the region from the rule of the Turks.] • *ibid.*, "Die alte Eisengewinnungsindustrie in Bulgarien," *Geologie*, **20** (1971), Heft 4/5, p. 597-608, 11 illus. [On the old iron producing industry in Bulgaria.] • *ibid.*, *Starata zhelezodobivna industriia v Bulgariia.* Sofiia, BAN, 1978. 206 p., illus. [On Iron mines and the mining history in Bulgaria. Text in Bulgarian Summary in English and French.] • *ibid.*, *Poleznite izkopaemi ot vremeto na trakite.* Sofiia, Izd-vo na Bulgarskata akademiia na nauki, 1987. 133 p., illus. [Metal and non-metalliferrous resources in the time of the Thracians in Bulgarian. Bibliography, p. 111-115.] • Ivan Kostov, V. Breskovska, J. Mincheva-Stefanova, and G.N. Kirov., *Mineralite v Bulgariia.* Sofia, Izdatelstvo Bulgarskata Akademiya Naukite, 1964. 540 p. [Topographical mineralogy of Bulgaria, that contains a short history of the science in the country and a bibliography on pages 518-532.] • Rusian Kostov., "The mineralogical education in Bulgaria as exposed in textbooks from the XIX and first half of the XX century," *Annual of the University of Mining and Geology "St. Ivan Rilski"*, part I, Geology, **45** (2002), p. 129-132. • E. Maksimov., "Der alte Erzbergbau Bulgariens," *Geologie*, **20** (1971), Heft 4/5, p. 553-561, 21 illus. [Ore mining in Bulgaria in olden times.] • S. Tchorbadjiev., "The early days of chemistry in Bulgaria," *Centaurus*, **12** (1968), p. 289-302.

[1241] Further historical information may be found in: Helvi Hödrejärv., "History of analytical chemistry in Estonia (1800-1950)," *Journal Fresenius' Journal of Analytical Chemistry*, **357** (1997), no. 2, p. 191-196. • Herbert Viiding and D. Kaljo., Историиа геологических наук в Естонии [Istoriia geologicheskikh nauk v Estonii]. Tallin, Valgus, 1986. 358, [2] p., illus. [History of geological science in Estonia]

[1242] Further historical information may be found in: Janis Stradinš., *Etides par Latvijas zinatnu pagatni.* Riga, "Zinatne," 1982. 393 p., illus. [This history of science in Latvia contains a bibliography on pages 304-339.]

[1243] Further historical information may be found in: Algimantas Grigelis and I. Skuodené., "К истории геолограчецких исследовании б Литве б начале XIX века," (pp. 121-127) in: *Historia Kontaktów Polsko-Rosyjskich w Dziedzinie Geologii i Geografii.* Wrocław, 1972. 425 p. [History of geological studies in Lithuania in the 19th century.] • Algimantas Grigelis., *Lietuvos TSR geologijos istorija.* Vilnius, Lithuanian SSR, Mosklas, 1981. 260 p., illus. [This history of geological science in Lithuania is in Lithuanian with summaries in Russian and English.]

[1244] Further historical information may be found in: Al Codarcea., "O sută de ani de cercetări geologice în România," *Studii şi Cercetări de Geologie, Geofizică, Geografie*, Seria Geologie, **11** (1966), no. 2, p. 180-196. [Notes on the geological research of Romania.] • Paulina Hirtopanu., *Mineralogia centurii manganifere din Muntii Bistritei este titlul integral al cartii.* Bucharest, Editura Cartea Univesitara, 2004. 352 p., illus. • Nicolae Maghiar and Štefan Olteanu., *Din istoria mineritului în România.* Bucureşti, Editura ştiintîfică, 1970. 335 p., illus. [History of the mines and mineral resources of Romania.] • G. Popescu., "Brief history of mining in northern Romania," *Romanian Journal of Mineralogy*, **77** (1995), p. 7-10. • Dan Rădulescu and Radu Dimitrescu., *Mineralogia topografica a României.* Bucureşti, Editura Academiei Republicii Socialiste România, 1966. 376 p., one map. [This topographical mineralogy of Romania contains a few pages describing the history of mineral studies in the country and a long bibliography on pages [347]-376.] • Aurel Sîntimbrean., *Muzeul Mineritului din Rosîa Montană.* Bucureşti, Editura Sport-Turism, 1989. 216 p., [32] p. of plates, illus. [History of the mines and mineral resources of Rošia Montană in Romania.; ISBN 9734100297.] • Volker Wollmann., *Mineritul metalifer, extragerea sarii şi carierele de piatra în Dacia romana = Der Erzbergbau, die Salzgewinnung und die Steinbrüche im römischen Dakien.* Cluj-Napoca, Muzeul Nătional de Istorie a Transilvaniei, 1996. 469, cxvi p., illus., maps. [History of the mines and mineral resources of Romania, including quarries and salt mines during Roman times.; ISBN 9730002533.]

1966 Dan Rădulescu and Radu Dimitrescu., *Mineralogia topografica a României*. Bucureşti, Editura Academiei Republicii Socialiste România, 1966. 376 p., one map. [This topographical mineralogy of Romania contains a few pages describing the history of mineral studies in the country and a long bibliography on pages [347]-376.].

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2006 Paulina Hirtopanu., *Atlas mineralogic o suta de minerale pentru o suta de ani = Mineralogical atlas one hundred minerals for one hundred years*. Bucureşti, Cartea Universitara, 2006. 94 p., illus. [ISBN 973-731-306-2.].

Carpathians

2002 Sándor Szakáll, ed., *Minerals of the Carpathians*. Prague, Granit, 2002. 479, [1] p., illus. [A topographical study, with considerable historical information, on the minerals of the Carpathian Mountains in central Europe.].

### 11.2.6.1.1 Poland (Polska)[1245]

Poland is located in central Europe, bounded in the north by the Baltic Sea and Kaliningrad Oblast of Russia, on the northeast by Lithuania, on the east by Belarus and Ukraine, on the south by Slovakia and the Czech Republic, and on the west by Germany. While Poles trace their roots to prehistoric times, as a nation, present-day Poland dates its origins to the year 966, when the foundation of the country was laid. That was the year when the rulers accepted Christianity from the south.

In Poland's lengthy and tumultuous history, there were periods when the region was rich in art, poetry, religious experience, scientific advances and economic prosperity. During the second half of the 18th century the Kingdom of Poland was a country which differed from present-day Poland in many important ways. Its territory included all of what we now call Lithuania, Belarus and half of contemporary Ukraine. On the other hand, nearly half of the contemporary area of Poland then belonged to Prussia (or, less precisely to Germany). Between 1772 and 1795 the entire territory of the Kingdom of Poland was divided between Prussia, Austria and Russia. During those so-called Partitions of Poland, Prussia acquired the western regions of Poland, especially, those, which were later renamed to West Prussia and Province of Posen. The southern Polish territories around Krakow and Lwów were incorporated into the Austrian Empire and renamed 'Galicia'. The central and eastern provinces of Poland were taken over by the Russian Empire. Between 1795 and 1918, Poland disappeared from Europe's maps, being incorporated wholly into other countries. It would only re-emerge once more independent and proud at the end of World War I, when an

[1245] Further historical information may be found in: Z.H. Gąsiorowska., "Książka adresowa mineralogów z pierwszej polowy XIX wieku," *Wladomości Muzeum Ziemi*, **5** (1951), pt. 2, p. 463-468. [Short history of mineralogy in Poland in the 19th century.] • K. Koziorowski., "Materjały do dziejów mineralogii w Polsce," *Poradnik dla Samouków*, n.s., **5** (1925), p. 627-701. [Material on the history of mineralogy in Poland.] • *ibid.*, "Histoire sommaire de la minéralogie en Pologne," (pp. 65-86), in: *Histoire sommaire des sciences en Pologne. Publiee a l'occasion du VIIe Congres international des sciences historiques*. Cracovie, Drukarnia Narodowa, 1933. [4], [1]-154, [2] p. [Summary of the history of mineralogy in Poland, including many brief biographical details, with full name, and dates of birth and death.] • S. Kreutz., "Historja nauk mineralogicznych," *Poradnik dla Samouków, T.V. Mineralogi i Petrografia Wskazowki Methody czive dla Studjwjacych*, **5** (1925), p. 599-626. [Brief history of the development of scientific mineralogy with special reference to its growth in Poland.] • J. Morozewicz and T.J. Wolny., "Przegląd historyczny podeęczników mineralogji w Polsce," (pp. i-liv) in: G.von Tschermak, *Podręcznik Mineralogii. Wydanie polskie drugie*. Wg I-go wyd. polskiego oraz 9-go wyd. niem. uzupełnili J. Morozewicz i T.J. Woyno. Warszawa, Kasa im J. Mianowskiego, 1931. [Contains a history of mineralogy in Poland to 1930.] • J. Tokarski., *Nauki mineralogiczne w Polsce*. Kraków, 1948. [1]-38 p. [Survey of the history of mineralogy in Poland, reviewing principally the 19th and early 20th centuries.] • P. Vogel., *Mineralogia w Polsce w w XVI wieku*. Sprawozdanie Dyrekeji Gimnazjum w Wadowicach za rok szkolny 1908. Wadowice, 1908, pp. 3-32. [Mineralogy in Poland in the 16th century.] • Hans Völkel., *Mineralogen und Geologen in Breslau. Geschichte der Geowissenschaften an der Universität Breslau von 1811 bis 1945*. Haltern, Bode, 2002. 223 p., illus. [History of mineralogy and geology at Breslau University.; ISBN 3925094806.] • Zbignew Wójcik., "Uczniowie Abrahama Gottloba Wernera w Polsce", *Studia i Materiały z Dziejów Nauki Polskiej*, Serie C., **17** (1972), p. 77-121. [Study about Werner's students in Polland.] • *ibid.*, "Wiadomości o Dawnych Polskich Kolekcjach Geologicznych w Rosji," (pp. 373-390) in: *Historia Kontaktów Polsko-Rosyjskich w Dziedzinie Geologii i Geografii*. Wrocław, 1972. 425 p. [On the ancient Polish geological collections in Russia.] • *ibid.*, "Nauki geologiczne w Warszawie w latach 1869-1915," (pp. 391-422) in: *Historia Kontaktów Polsko-Rosyjskich w Dziedzinie Geologii i Geografii*. Wrocław, 1972. 425 p. [Geological sciences in Warsaw in the period 1869-1915.] • *ibid.*, "Historia geologii w Polsce: Wazniejsze osiagniecia i perspektywy rozwojowe," *Kwartalnik Historii Nauki i Techniki*, **35** (1990), p. 603-624. • *ibid.*, *Znajomość wazniejszyck kopalin na ziemiach polskich w epoch Oświecenia*, **37** (1992), no. 2, p. 33-65. [Knowledge of mineralogy in Poland during the Enlightenment.]

independent Republic of Poland was restored.

Mining industry reached a considerable degree of development in old Poland. This fact is attested to by the existence of the ancient saltworks near Krakow of Wieliczka and Bochnia. Mining of the siver-bearing black lead ores of Olkusz reached its climax towards the end of the 16th century. But all this activity had only a small influence on the early development of mineralogy in Poland. The early herbals are apparently the first printed accounts of minerals in Polish literature. The first Polish herbal, containing concepts on different natural history subjects, including mentions of the local mines and minerals, was the herbal of Stefan Falimierz (1534).[1246] Other early Polish herbals include Hieronim Spiczynski (1556),[1247] Marcin Siennik (1568),[1248] Marcin Urzędow (1595),[1249] and Szymon Syreński (1613).[1250] These works treat all the objects of natural history from the point of view of their use in medicine. This restricted their mineralogical content because they deal only with minerals with supposed medical virtues, thus limiting the number of the minerals described to less than one hundred.

The whole of mineralogical science, such as the scholars of the end of the seventeenth century understood it, is found in the succinct work of Joannes Jonston [1603-1675], published in 1661 in Leipzig, under the title *Notifia Regni Mineralis seu Subterraneorum Catalogus*. Born into a Scottish family that had reestablished itself in Poland, Jonston called himself, "Scoto-Polonus". Born in Szamotuly, Poland in 1603, he received a medical degree from Leiden. After that the major part of his life was spent in Leszno at the Court of Boguslas Leszczynski, where Jonston worked as personal physician and tutor. In his book he classifies minerals into five groups, namely: 1), earths, 2) solidified juices, 3) resins, 4) stones, and 5) metals.[1251] It is one of the best systems of this period with its foundation based on the previous work of Agricola; however, Jonston attempts to improve the classification with his own ideas. Consequently, new combinations not seen before, arise. It is based on simple external qualities like the state of aggregation, degree of limpidity, color, etc. It could not be differently. At that time, analytical chemistry was still camoflauged in the alchemical writings, and there were no other basis for systematic mineralogy other than the phyisical characteristics. A note at the end of Jonston's book indicated that it was conceived as a draft to a larger work, but this other book never appeared.

The next mineralogical treatise was that of the Jesuit scholar, Adalbert Tylkowski [1624-1695], professor at the Academy of Wilno. He was famous among his contemporaries for his scholarship, and the many books he authored were printed in multiple editions in Poland and abroad. The *Physica Curiosa Pars Octava* is most significant for the history of the natural science in the last quarter of the 17th century in Poland. It is one part of a general scientific philosophical expose that

[1246] Stefan Falimierz., *O ziolach y o moczy gich*. [Krakow,] Florian Vnglerius ..., 1534. [36], 156, 23, 42, 59, 119, 1 $\ell$. (woodcuts). One of the most lavishly illustrated volumes published in Poland in the early sixteenth century, Stefan Falimierzs *O ziolach y o moczy gich* is also the first real encyclopedia of natural science in Polish. It was compiled from various Latin herbals, and includes such topics as herbs and their use in medicines, the medicinal uses of birds, animals, and fish, stones and minerals, and a variety of medical procedures such as bloodletting.

[1247] Hieronim Spiczyński., *O Ziołach*. Cracoviae, 1556. • J. Szostak., "Autorzy pierwszych zielników polskich - Stefa Falimirz, Hieronim Spiczyński i Marcin Siennik,," *Archiwum Historii Medycyny (Warsz)*., **40** (1977), no. 3, p. 277-289. [Authors of the first Polish herbal: Stefan Falimirz, Hieronim Spiczynski, Marcin Siennik]

[1248] Marcin Siennik., *Herbarz, to jest ziól tutecznych, postronnych i zamorskich opisanie*. Kraków, 1568.

[1249] Marcin Urzędow., *Herbarz polski, to iest o przyrodzenin ziół y drzew rozmaitych, y innych rzeczy do lekarztw nalezacych, księgi dwoie, Doctora Marcini Urzędowa, i.e. Herbarium polonicum h.e. de natura herbarum et arborum variarum atque aliarum rerum ad pharmaca pertinentium libri duo*. W. Krakowie, w drukárni Lázárzowéy, 1595. [6], 488 p.

[1250] Szymon Syreński., *Zielnik, Herbarzem z iezyka lacinskiego zowia, to iest Opisanie wlasne imion, ksztaltu ... y mocy ziol wszelakich drzew... takze trunków, syropów ... przytym o ziemiach y glinkach roznych, o kruscach, perlach y drogich kamieniach, tez o zwierzetach ... od Dioscorida, z przydaniem y dostatecznym dokladem z wielu innych tey materiey pisacych ... polskiem iezykiem zebrany y na VIII ksiag rozlozony...* przez D. Simona Syrenniusa. Dokonczon ten Zielnik w Krakowie, w drukarni Bazylego Skalskiego, w marcu roku panskiego 1613. Cracovie, 1613. 1540 p.

[1251] Beekman 1906: p. 17-18.

appeared in Oliwa in fifteen volumes between 1680 and 1691. Dedicated to King Joannes III, Tylkowski completed this work in 1682, as is mentioned in an interesting letter from Kircher, who recommends the text for publication. Tylkowski is devoted to the analysis of the multiple problems, including physics, chemistry, astronomy, physical geography, meteorology, biology, and finally mineralogy. He similtaneously treats several questions related to the object of the analysis. In his *Physica* of 5,301 total pages, 374 are devoted to the mineral topics. Tylkowski uses the classification of Albertus Magnus in arrangin his minerals. To the three groups, earths, stones and metals, he adds only that of the subterranean waters. He summarizes the descriptions of the minerals, and rarely speaks of their localities. He also investigates several aspects dealing with general questions. He explains their origin, their phyisical qualities, and their regular forms. If Tylkowski believes that a specific mineral has medical virtues he mentions the topic, sometimes undertaking to explain in great depth the healing action on humans.

The location of where minerals are found in Poland was carefully collected in the general natural history book of the Jesuit scholar Gabriel Rzączyński [1664-1737], published in Sandomierz in 1721 under the title *Historia Naturalis Curiosa Regni Poloniae, Magni Ducatus Lithuaniae, Annexarumque Provinciarum*,[1252] and in its supplement published in Gdansk in 1724, under the title *Aucluarium Hisloriae Naluralis Curiosae Regni Poloniae*. Rzáczyùski performed his initial research in the libraries that provided him with raw material for the work. He added to this information observations of many correspondants and his own observations made during his travels through the country.

Rzączyński travelled widely through out Poland, but remained longer in three places: in Sandomierz, in Ostrôg in Volhynie and in Gdansk. The last city was at the time the center of the most enthusiastic studies of natural history, which caused the formation of several natural history collections in Gdansk. In his book Rzączyński generally quotes Jakob Theodor Klein [1685-1759] and that of the physician Christoph Gottwald [1636-1680]. Rzączyński mentions that these museums concentrated on objects originating from various areas of Poland, and thus these museums of Gdansk provided him with much information, which caused him to extend his stay in the city. Unfortunately, he died before his work was complete, although the information he gathered was incorporated into his posthumous work.

In Polish natural science, Rzączyński is astonishing not only because of the many studies that he made, but also with the care of his compilation. However, it is a surprise as to the lack of criticism he includes in his descriptions. Sometimes Rzączyński announces it as a personal opinion that he has obtained as a juxtapostion of several, even contradictory, other authors. In spite of this defect, the work is a significant cotribution to Polish scientific literature. Rzączyński gave the largest physiographical description of Poland that remained unchallenged for many years. He also treats the natural science before Poland was divided through politics and war.

At the end of the 17th century, the period of Stanislas-Auguste brought into Poland a new age of scientific investigation. Through the efforts of eminent individuals like King Leszczyński, Prince Jabłonowski, Stanislas Konarski, the brothers Zaluski and others, the Polish nation broke away from its stagnation and began to reform. Under the influence of the King, in conjunction with the business establishment, a new vitality spread to all the fields of culture. This movement further increased after the first division of Poland, when the threat of lost independence forced a reevaluation of Polish culture. The scientific work thus became increasingly intense. The "Commission of the National Education" is then formed, which is the first state ministry for education anywhere in Europe. Also created was the "Company for the Elementary Books"

[1252] Gabriel Rzączyński., Historia naturalis curiosa Regni Poloniae, MagniDucatusLituaniae, annexarumq; provinciarum in tractatus XX divisa: Ex scriptoribus probatis, servata primigenia eorum phrasi in locis plurimis, ex M.S.S. variis, Testibus oculatis, relationibus fide dignis, experimentis, desumpta opera P. Gabrielis Rzaczynski Soc. Jesu. Typis Collegii Soc. Jesu, 1721. [14], 456, [16] p.

that undertook to reform the textbooks of Higher Schools of education. This intellectual movement contributed advantageously to the development of the study of natural science in Poland, including mineralogy. The new courses of these sciences were first introduced into the public schools in 1740, followed by the colleges of the Jesuits. Permanent chairs of natural history were established at the reformed universites. Natural science studies was also introduced into the circulum of the secondary schools through the new textbooks. The first handbooks of mineralogy in the Polish language indeed appear during the reign of Stanislas-Auguste. Similtaneously, it is at this time that a more general interest in the mineral kingdom appears, being expressed by the formation of various mineralogical collections.

In 1783 the *Historia Naturalna Królestwa Polskiego* (Natural History of the Polish Kingdom) by Remigi Ladowski [1738-1798] the original idea of Rzączyński is popularized. Namely, that it is necessary to describe the physiography of the native land. Due to the purity of its descriptive language and its encyclopaedic character, the book received a good reception. It was published twice and even translated into German. However, the descriptions of minerals found in Poland, Lithuania and in other provinces, are nothing more than a summary of the descriptions found in Rzączyński.

The work of Krzysztof Kluk [1739-1796], *Rzeczy Kopalnych Osobliwie Zdatniejszych Szukanie, Poznanie i Zazycie* (Useful Mineral Objects: How to Find, Recognize and Use Them) published in Warsaw in 1781 was the first work devoted to mineralogy published in Polish. Kluk, one of the great naturalists of the 18th century, was cited as an authority especially by Lehmann and Wallerius. The work is written, however, not for the scholar but for the amateur. He condemns the belief in the magical properties of minerals, distinguishes between chemistry and alchemy, describing the later as misleading and hypocritical, and debunks the simple fables attributed to the supernatural virtues of minerals. His work constitutes a significant stage in the development of the Polish mineralogical vocabulary. His is the first to introduce many of the words and expressions that consequently were established in the Polish terminology. He also avoids the useless polonisation of the names of various universally accepted minerals, like: talc, onyx, agate, jasper, spar, quartz. Instead, he uses a simple and clear language and a style almost like that of a storyteller, which brought many readers to him. His work, published in three editions, was ultimately admitted by the Commission of National Education to be used as a textbook in higher education.

Other contributions to the mineralogy of Poland based upon actual field observation began to appear. Jan Dominik Piotr Jaśkiewicz [1749-1809] had his higher education in Vienna. It is there that in 1775 he acquired the degree of the doctor of philosophy and medicine. In 1782, he was appointed professor of natural history and chemistry at the University of Krakow, which had recently been reorganized. Before undertaking this appointment, Jaskiewicz visited the palatinats of Krakow and Sandomierz for the mineralogical and botanical studies. At this point in time he discovered the layers of coal in Siersza. Jaskiewicz also searched for other mineral resources, which he discovered during his travels through Poland. He published a study on the different layers of the porphyry between Miçkinia and Tenczynek near Krakow and an essay on the mineral water of Krzeszowice. A number of his scientific works were never published and were preserved in manuscript at least until World War II. He was a professor in Krakow for only five years (1782-1787), when he became director of the coal mines near Krakow.

Jan Filip von Carosi [1744-1801], general manager of mines, carried out between 1778 and 1780 work on the exploration of the territory in the southwest of Poland. He published the results of this research in a 1781 work in two volumes, *Reisen durch verschiedene polnische Provinzen mineralischen und andern Inhalts*. One of the most significant results of these mineralogical expeditions was the discovery salt layers, or, at least, salt springs. Feeling the loss of the saltworks of Wieliczka and Bochnia when Austria seized the territory, the Polish goverment sought new saltworks which

could replace them. Carosi also gives valuable information on the copper, iron, lead mines that he had visited. In his information on some mines surrounding Kielce and Chęciny he gives the lists of minerals collected, and thoroughly describes them according to the method of Werner. Carosi also gives his observations on the formation of flint and quartz in a work published in Krakow in 1783, in French, under the title *Sur la Génération du Silex et du Quarz en Partie*.

In his work, *La Description des Usines Polonaises de Fer* (Warsaw, 1782), Joseph Osinski [????-????] described the various species of iron ore recovered in Poland, especially those found in the districts of Radom and Opoczno, the principal seat of the iron industry in Poland of the time. This work enriched the Polish mineralogical and mining vocabulary by utilizing many expressions drawn from among the miners. The work of Hippolyte Kownacki [????-????], whose anonymous publication appeared in Warsaw in 1791, was titled, *Sur l'Antiguité des Mines et de la Métallurgie dans le Domaine de Sławków*. It also contains some contributions to the mineralogy of Poland.

Michel-Jean Borch [1753-1810] occupies a special place among the mineralogical scholars during the time of Stanislas-Auguste. However, he did not take an active part in the intellectual life of the country. Instead, he published in French his major works, devoted to the mineralogy of Sicily, "to which, though foreign, he had affectionately stuck," and where he staid two years. These works were highly regarded by scholars of his time. A list of his works: *Lithographie Sicilienne* (Naples, 1777), *Lythologie Sicilienne ou Connaissance de la Nature des Pierres de la Sicile* (Rome, 1778), *Minéralogie Sicilienne Docimastique et Métallurgique ou Connaissance de Tous les Minéraux que Produit l'Isle de Sicile* (Turin, 1780), *Lettres sur la Sicile et sur l'isle de Malthe* (Turin, 1782).

Chairs of natural history were founded at several schools of higher education in Poland, and it is to them that the fate of mineralogy is closely bound. Therefore, the study of the development of mineralogy at the universities reflects its development in the country. Stabilization of the political situation and a suitable budget are the principal conditions for the favorable development of the universities. In fact the Polish schools in the part annexed by Russia entered a Renaissance at the end of the 18th century.

### Wilno

In the 18th century, the University of Wilno was considered the best of the Polish universities, while those the University of Jagellonne in Kraków was to some degree its antithesis. From 1794 to 1815, Krakow belonged successively to four different countries. Each external change was immediately echoed in the organization of the University and the course of its work. It is therefore necessary to admire the energy of this generation that almost always resumed stopped work, instead of losing courage during these continual changes.

In the 18th century, the names of Haüy and Werner were famous in mineralogy, as those people that gave the science its form by presenting new methods and new theories. They were also famous among the scholars of Poland, in spite of the political miseries of this time. The fame of Werner attracted many Poles to study in Freiberg. Here may be mentioned Symonowicz, Józef Tomaszewski [1783-1844], and Borkowski. Some of these students were not satisfied with their studies in Freiberg, and supplemented them by going to Paris. This is why, in 1820, the "Company of the Friends of Sciences of Warsaw" registered among its foreign members Charles Biot and René Just Haüy of the French Institute, "in consideration of the particular care which they took to help the young Poles seeking their lights in Paris."

The University of Wilno in Lithuania did not have a special chair of mineralogy. There the science was taught by the professors of natural history. It is only after the transformation of the school into an Imperial University that the chair of mineralogy was created. The first instructor to hold the position was Romain Symonowicz [1763-1813]. From 1801, Symonowicz studied mineralogy abroad, mostly under the direction

of Werner. He gathered together an immense collection of minerals, selected with care and at great expenses, which he brought back to Poland. In 1806, he published an important mineralogical work titled, *O Stanie Dzisieyszym Mineralogii* (The Present State of Mineralogy). This book generally follows Werner in its organization of mineralogy and geology, but also contains a comparision to the system of the French mineralogist Haüy. Here are given all of the objections made to that system by the followers of Werner. B. Jundziłł rather severely criticized the work of Symonowicz. His criticisms were answered by Symonowicz in a special writing, where each objection is carefully refuted. This controversy was extremely instructive for the public, by characterizing the two tendencies of mineralogy.

Felix Drzewinski [1788-c1840], professor of physics, succeeded Symonowicz in the chair of mineralogy after the later's death in 1813. He instructed in mineralogy for three years (1814-1817). He also wrote the first university level handbook of mineralogy in the Polish language. It was published in Wilno in 1816, under the title, *Poczatki Mineralogii Podlug Wernera Ulozone dla Sluchaczów Akademickich* (Introduction to Mineralogy Arranged after Werner for Academic Learners). This work, giving a good picture of the science of the time, was for many years the most complete handbook of mineralogy in Poland. It then became the model for several other authors. Norbert Alfons Kumelski [1802-1853] authored *Krótki wyklad Mineralogia podlug Zasad Wernera* (Short Course of Mineralogy according to Werner) that was published in Wilno in 1826. Ignace Horodecki [1776-1824] was named in 1817 to the chair of mineralogy. After his death in 1824, these courses were given to Ignacy Jakowicki [1797-1847], who taught mineralogy until 1831, when the University of Wilno was abolished. He published in 1825, a *Krótki Wykład Oryktognozyi i Geognozyi Podług Ostatniego układu Wernera* (Summary Talk of Oryclognosy and Geognosy according to the Theories of Werner), whose second edition appeared in 1827. Among his geological work, it is necessary to mention the *Obserwacje Geognostyczne w Guberniach Zachodnich i Poludniowych Panstwa Rosyjskiego* (Geognostic Observations in the Western and Southern Regions of the Russian State), published in 1831. He also made many contributions to the mineralogy of Poland, which were published in the Polish journals.

Thanks to those first handbooks, in the modest history of Polish mineralogy, Wilno occupies a place of honor, showing the level of the science of the time. All of these handbooks were written according to the theories of Werner. Although the doctrines of Haüy were not ignored in Wilno, the theories of Werner were more suitable for teaching elementary mineralogy.

In western Poland, occupied by Russia, the College of Volhynie, founded by Czacki with Józef Krzemieniec [1813-1888], had a rich mineralogical cabinet. By the early 19th century it contained 15,538 specimens, but the college was closed after the Polish insurrection of 1831. The mineral cabinet, together with other collections of natural history and the library, were all then moved to the University recently founded in Kiev.

Two professors of the College deserve our special attention here. The first, it is Étienne Zienowicz, professor of chemistry and mineralogy with Krzemieniec, later senior of philosophical Faculty with Kiev. He carefully studied the mineralogy and the geology of Volhynie and Podolie. The other, is Albert Zborzewski, professor of mathematics. He was devoted to palaeontology and he compiled lists of the fossils, rocks and minerals of Volhynie, Podolie and the Ukraine. His personal collection reached over time 20,000 specimens. It was used by Karl Eduard Ivanovich Eichwald [1795-1876] with great utility when he wrote in 1834 his *Naturhistorische Skizze von Lithauen, Volhynien und Podolien in geognostisch-mineralogischer, botanischer und zoologischer Hinsicht* (Draft Naturalist of Lithuania, Podolie, Volhynie, from the Point of View Geognostic, Mineralogical, Botanical and Zoological).[1253] This work, written

[1253] Karl Eduard Ivanovich Eichwald., *Naturhistorische*

in the German language, is still useful today for giving information on the natural history of these regions.

The years 1831 to 1862 form the saddest period in the history of science in Poland. The unsuccessful insurrection of November 1831 had as a consequence the supression of Polish science. Many centers of intellectual life, whose scientific accomplishments had been so sharp, and which still promised a richer progress, were abolished. The University of Wilno was closed, at the apogee of its flowering. Its rich collections, including the mineralogical cabinet, were transported to Russia. The College of Krzemieniec had the same fate. The Company of the Friends of Sciences of Warsaw was dissolved, with its library and its valuable collections taken as spoils of war by the triumphent enemies. The University of Warsaw was closed for fifteen years. Even the number of the secondary and primary schools declined sharply. The persecution of the intelligent classes, a principal goal of the invaders of Poland, became singularly atrocious in these times. The most educated spheres being decimated by emigration and exile, and the organization of the nation weaking considerably. During the years which immediately follow the November revolution the intellectual life of the entire country almost dies completely except for the efforts of a few generous patriots. Only one higher school survives in all Poland. It is the University of Krakow.

The remarkable scientific activity of an emigrant, Ignace Domeyko [1801-1889], the greatest Polish mineralogist besides Borkowski, had a profound influence on his adopted country. Born in 1801, Domeyko completed in 1822 his studies of physics and mathematics at the University of Wilno. The Insurrection of November forced him into exile. He matriculated at the School of the Mines of Paris, from where he graduated as a mining engineer. In 1838, he was named professor of physics and chemistry at the School of the Mines recently created in Coquimbo, Chile. The stay in this country, projected for six years, lasted until 1884. Concurrent to his teaching duties, he devoted himself to the mineralogical and geological studies of Chile, as well as developing the local mining industry. He also published works on the meteorology, mineral waters, and ideas of reforming the school system of Chile. He also worked to improve the lives of Indians of Araucanie. Besides his numerous papers, Domeyko prepared several textbooks, including the important *Elementos de Mineralogia* (1st ed., Serena, 1845). Based on his wide fields of study, he is today remembered as not only one of the great mineralogists and geologists of Chile but one of the most eminent pioneers of culture and science in South America. In the last years of his life, he made a return visit to his native Poland before returning to Chile where he died in 1889.

**Warsaw**

In Warsaw, the "Company of the Friends of Sciences" was the principal center of the intellectual movement during the first three decades of the 19th Century. Created immediately after the division of Poland, the purpose of the society was to expand the intellectual level of the nation. The Company produced only a modest result in the field of mineralogy. In the published transactions of the Company there are reports of the progress of mineralogy. Stanislaw Staszic [1755-1826] sought to a stabilize the mineralogical terminology, and Lucjan Pawlowicz [?-1899] discussed the mineralogical richnesses of Poland and gives lists of minerals in various areas of the country. At this point Staszic collected together his essays in 1815, uniting them into the work *O Ziemiorodztwie Karpatów i Innych Gór i Równin Polski* (On the Earth Resources of Carpathians and other Mountains and Lowlands of Poland). This work, very significant in the scientific literature of Poland, constitutes the first description of the geological structure of Poland in Polish language, providing the first complete and precise information on the minerals of Poland. Staszic appreciated the range of the natural

*Skizze von Lithauen, Volhynien und Podolien in geognostisch-mineralogischer, botanischer und zoologischer Hinsicht*. Wilna, auf Kosten des Verfassers gedruckt bei Joseph Zawadzki, 1830. [6], 256 p., 2 lithographic plates.

resources of the country, thus giving suitable advice on their exploitation. With regard to mineralogy, these tendencies were expressed by the organization of a mineralogical cabinet, composed of gifts offered by the members of the Company. Staszic took part in it in the forefront. Already in 1814, he offered to the Company his own collection of natural history. Then, as general manager of mines, he gave to the Company minerals sent from various mines of the country. In 1823, A. Pawlowicz put the mineralogical collection of the Company in order. By the time the Company ceased to exist, the cabinet contained 8,559 mineral specimens, which ultimately were transported to St. Petersburg.

In 1811 in Warsaw, Franciszek Ksawery Puławski [????-????] published his *Wiadomosc Mineralogiczna Poznawania Róznych Kruszców i Kamieni w Ziemi Znajdujacych Sie* (Mineralogical Information on Recognition of Various Ores and Stones Occurring in the Earth). This is an introduction to the search of the various minerals and ores contained in the interior of the earth and reviews of the newest discoveries in the field of mineralogy.

Two professors occupied successively the chair of mineralogy at the University of Warsaw: J.F. Hoffmann [????-????] and A. Pawlowicz [????-????]. The last was a mineralogist and geologist by profession. After having completed his higher education at Wilno, he supplemented them through a few years of foreign studies and travels. An untimely death stopped him in his 41st year of his scientific activity, which he had undertaken after his return to Poland. His essay, *????* (Origins and Qualities of Basalt), published in 1822, is his most significant work.

Apart from Warsaw, mineralogy was more generally studied in Kielce, in the Academic School of Mines founded by Staszic in 1816. Imitating the successful School of Mines in Freiberg, the Polish government appointed the Saxon Jerzy Bogumil Pusch [1791-1846] as professor of chemistry and metallurgy in this school. After arriving in Poland, Pusch began research into the geology of the country that was published after a decade of investigation as *Geognostic Description of Poland and other Countries Located at North of Carpathes*. This work, written in German, appeared in two volumes with an atlas of plates in 1833 and 1836. It was preceded in 1830 by a short summary, translated into Polish from the German manuscript by Adam Maksymilian Kitajewski [1789-1837]. The work of Pusch is the basic starting point of all the modern geological studies of Poland. Pusch with Ludwik Zejszner [1807-1871] is therefore regarded as the creator of this science in Poland. There is also much precise and significant information on the mineralogy of Poland contained in this work.

In Warsaw, intellectual animation began again towards the end of 1840, when the creation of the periodical *Bibljoteka Warszawska* occurs. The founders of this national review proposed to make it a center of intellectual life. They sought scholars in the various fields of science to contribute their work and stimulated intellectual development by sponsoring contests. The beneficial activity of the editors of the *Bibljoteka Warszawska* was not limited to this periodical. It is through them that several advantageous societies for science in Poland formed. The collective work of Beudant, Jussieu and Milne-Edwards, *Wykład Początków Mineralogji i Geologii Przeł* (Elementary Course of Natural History) was translated from French under their direction and published in 1848. The translation was undertaken to satisfy the great need for textbooks in Poland. It aimed at equaling the French original. Jerome Labçcki, author of the *History of Mining Industry in Poland*, translated the famous minerlaogical work of Beudant, *Mineralogy and Geology*. This work, supplemented by concepts concerning Poland, became the handbook of mineralogy to several generations of Polish students. The merit of Labçcki was also to publish a *Dictionary of the Terms Employed in Mining Industry and Sciences which Refer to it*, where he collected carefully and, learnedly all the treasure of the mineralogical and geological expressions in Polish. This work appeared in Warsaw after the death of the author, in 1868.

Closed in 1831, the University of Warsaw was reopened in 1862, under the name of Higher School. Karol Jurkiewicz [1822-1908] was put in charge of the course of mineralogy there. He was devoted especially to the popularization of the science. He was also a collector of minerals. When the school closed in 1869, Jurkiewicz taught mineralogy up to 1879 at the Russian University, opened in its place. After his retirement, the direction of the mineralogical Institute was withdrawn from the Polish control for 35 years.

The first foreign directors, Alexander Evgen'evic Lagorio [1852-1944] and Georg Wulff [1863-1925] were both capable in their appointments to the University. Lagorio, an eminent petrologist, adapted the mineralogical work of the Institute to modern standards. In 1898, Wulff, one of the most famous contemporary crystallographers, succeeded Lagorio. He moved to the University of Warsaw in 1909. In 1915, the Polish language finally became the standard language of the University and of the region.

### Krakow[1254]

At the University Jagiellonski in Krakow, mineralogy was introduced permanently into the program of studies at the University with the creation of the special chair of chemistry and natural history in 1780. Mention is made here of Balthasar Hacquet [1739-1815] and Alojzy Rafał Estreicher [1786-1852] among the professors who succeeded Józef Jackiewicz [????-????] (up to 1830) on this pulpit.

Ludwik Zejszner [1807-1871] was the most remarkable of the mineralogists who taught at Krakow between 1830 and 1862. In his many writings, he compiled many interesting and valuable observations on the minerals found in various places throughout Poland. He had two stints as an instructor at the University. He was also the author of two mineralogical handbooks that were used in his classes in mineralogy at Krakow. *Systemat Minerałów według zasad J.J. Berzeliusza* (Mineral Systematics according to J.J. Berzelius), published in Krakow in 1833, was the result of his first period of teaching (1830-1833). The second period of the teaching of Zejszner, lasted a longer time (1848-57), during which he contributed, *Początki Mineralogii według układu Gustawa Rose* (General Mineralogy according to J.J. Berzelius), appeared in 1861 in Warsaw, after the author had already left Krakow. Zejszner thereafter worked as a geologist. He did not contribute anything to the mineralogical field again, although he knew the literature of it. His two books were an invaluable contribution to the modest literature of Polish handbooks, giving the reader an extremely well formed state of the mineralogical science.

Another unsuccessful insurrection in 1863 marks another turning point in the history of mineralogy in Poland. Once again, as it was the case after 1830, an avalanche of misfortune overran the country, initially affecting the higher levels of society. However, the tendency to study nature and science was again soon followed in Poland. Many works on various branches of natural science appeared, and several centers of scientific activity were founded, including the Polish Academy of Science was founded in 1873 in Krakow. Other new industries based on the new discoveries were also introduced.

In Krakow, mineralogy was taught between 1862 and 1886 by Aloys Alth [1819-

[1254] S. Czarniecki and B. Schiller., "Nowe materialy do dziejów mineralogii na Uniwersytecie Jagiellońskim w okresie profesury Jana Jaśkiewicza," *Kwart. Historii Nauki i Techniki*, **9** (1964), p. 243-62. [New materials on the history of mineralogy in the Jagiellonian University during the professorship of Jan Jáskiewicz.] • *ibid.*, "Trzy rocznice gabinetu geologicznego Uniwersytetu Jagiellońskiego," *Kwart. Hist. Nauki i Techn.*, **7** (1962), p. 416-8. [Information on the geological cabinet of the University of Jagiellonski.] • *ibid.*, *Zarys historii geologii na Universytecie Jagiellonskim*. Krakow, Univsitat Jagiellon, 1964. 147 p., 17 illus. [Short history of geology at the University of Jagiellonski.] • A. Gawel., "Dwadziéscia lat Zakladu Mineralogicznego U.J. pod kierownictwem śp. prof. dr. Stefana Kreutza," *Rocznik Polskiego Towarzystwa Geologicznego (w Krakowie)*, **20** (1950), no. 1, p. 1-10. [History of the Mineralogical Institute of Jagiellonian University under the directorship of Stephan Kreutz.] • *ibid.*, "Rocznice Zakładu Mineralogicznego Uniwersytetu Jagiellońskiego 1783/4-1953/4; 1852-1952; 1887-1952," *Wszechświat.*, **69** (1955), p. 129-132. • S. Kreutz., "Kilka da historii Katedry i Zakladu Mineralogicnego Uniwersytetu Jagiellónskiego w Krakowi," *Wladomości Muzeum Ziemi*, **4** (1948), p. 275-287.



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by Curtis P. Schuh, Tucson, AZ—Edit Draft. [1200dpi]
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1886], who also did remarkable geological research in Podolie. He is the author of the university handbook of mineralogy, published in Krakow in 1868, under the title, *Zasady Mineralogii* (Elements of Mineralogy). In a collective work published in Krakow in 1864, titled, *Zaklady Uniwersyteckie w Krakowie* (The University Institutions in Krakow), Alth provides information on the history of the chair of mineralogy and the mineralogical cabinet of the University.[1255] Felix Kreutz succeeded Alth and taught up to 1903. From 1904, it is Józef Morozewicz who was in charge of the course of mineralogy in Krakow. He taught there until 1919. The mineralogical Institute of the University became under its able directors an animated center of the scientific movement, giving to Polish literature many essays of great value. The majority of this work is devoted to the study of the minerals that one finds in Poland.

One of the most eminent pupils of Morozewicz was Ladislas Pawlica [1886-1919], deceased at the 34 years age in 1919. His work relates mainly to the mineralogy and the petrography of Tatra. His last work, completed a few days before his unexpected death, was a draft describing the spathic iron ores of Starachowice. Apart from the University, special attention is due to the scientific activity of S. Zargczny, an instructor in the secondary education. His work, devoted initially to geology, is an abundant source of information on the minerals that are found around Krakow.

**Lwów**[1256]

The University of Lwów, founded in 1661 by King Jean-Jean-Casimir, fell into the hands of the Austrians when its territory was annexed. It was the first Polish institution to be subject to the political goals of the invaders. The teaching body of the University of Lwów was composed mostly of Austrian or German trained professors. These people, not versed in the Polish language, did not care for the students, and used their stay at Lwów as a stepping stone to other work. Rare exceptions were individuals with goodwill towards the country and students.

However, the first Polish mineralogist of merit, Stanislas Dunin Borkowski [1782-1851], came from this part of Poland where Lwów was the intellectual center. Born in 1782, he was devoted from his youth to natural science, especially mineralogy and geology. After his studies at Lwów, he went to the Academy Mines in Freiberg, to study there mineralogy under the direction of Werner. Convinced that a mineralogist could not do without chemical concepts, Borkowski travelled to Paris to take courses from the famous chemists, Vauquelin and Thénard. At the same time, he became an assistant in the laboratory of Vauquelin where he made chemical analyses, becoming an operator of great skill. In 1815 and 1816, he made a scientific trip to Italy. Returning to Poland, he was always devoted to mineralogy, publishing from 1809 the results of his studies in the French and German periodicals.

At his death in 1851, Borkowski was reknowned for his studies into the chemical composition of minerals, together with their physical and morphological properties. Among his most significant mineralogical work was an essay on the sodalite of Vesuvius, being first read at the meeting of the Academy of Science in Paris, on October 28, 1816. Sodalite, a significant mineral, until then only known from Greenland, was discovered at Vesuvius and was thoroughly studied by Borkowski. It is through him that its crystallographic form, hardness, the unit weight, all external qualities, and chemcial composition was defined. He also drew geological conclusions about the state of formation between Greenland and Vesuvius. The famous chemist Thomas Thomson translated this essay into English. The mineralogical work of Borkowski brought him considerable fame and a good reputation in the scientific circles of his time.

During the first years of this period,

[1255] Alojzy Alth., "Katedra i Gabinet Mineralog. Uniw. Jagiellońskiego" (pp. 234-265) in: *Zaklady Uniwersyteckie w Krakowie. Przyczynek do dziejow oswiaty i pamieciuselletniego islnienia Uniwersytetu Krakowskiego.* Krakowie, W Drukarni "Czasu" W. Kirchmayera, 1864. xv, 566 p.

[1256] S. Czarniecki., "Rękopisy Ludwika Zejsnera zachewane w Muzeum Naukowo–Przyrodnicym we Lwowie," *Prace Muzeum Ziemi*, no. 8 (1966), p. 155-158. [Ludwik Zejsnera and his directorship of the Science Museum at Lwów.]

the University of Lwów remained under the control of the Germans. From 1863 to 1868, mineralogy was taught there by Ferdinand Zirkel [1838-1912], celebrated German petrologist, who in 1868 left Lwów to fill the chair of mineralogy in Kiel. The first Polish professor of mineralogy at Lwów was Felix Kreutz. He published many petrographic, geological and crystallographic work. They are all characterized by the tendency to be absolutely accurate. Kreutz was in favor of experimental methods, which he applied with good results, especially in his mineralogical work. Kreutz was among the first in Poland to apply modern methods to the study of minerals, namely, the petrographic microscope and thin sections. From 1887, Kreutz taught mineralogy in Krakow. Between 1873 and 1917 the chair of mineralogy and geology at the Polytechnic School of Lwôw was occupied by J. Niediwiedzki [????-????], who authored some mineralogical works beside his many geological papers.

The increased interest in natural science also marked an increase in the number of the workers dedicated to mineralogy. Warsaw, Krakow, Lwów, were the starting points of good work of scientific significance. some of the scholars who published their mineralogical work and research prior to World War I were:

Felix Franz Xaver Kreutz [1844-1910]
F. Radomiński
Karol Stanislaw Olszewski [1846-1915]
Stanislaw Wawrzyniec Zaręczny [1848-1909]
Stanislaw Jósef Thugutt [1862-1956]
Józef Marian Morozewicz [1865-1941]
Zygmunt Weyberg [1872-1944]
J. Sioma
Stefan Kreutz [1883-1941]
Wladislaw Pawlica [1886-1919]
Tadeusz Jerzy Woyno [1884-1971]
Julian Tokarski [1883-1961]

### Collections of Minerals

Collections of minerals also began to be formed. Their history in Poland starts at approximately 1650. It is when the cabinet of natural history of Martin Bernitz, physician-ordinary to King Jean-Jean-Casimir began to collect. After the death of Bernitz, this cabinet became the property of Prince Domenica Radziwill. With the development of the natural science in the 18th century, more collections began to be formed. Those of Klein and Gottwald have already been mentioned. George Mniszech [????-????] founded the Musaeum Polonicum in 1775. Sponsored by the Commission of National Education, it was modeled on the Institue of Bologna and the British Museum, while recognizing that Poland would have difficulty competing on an equal footing with them, Mniszech wanted to thus limit himself to the formation of a more modest institute, being initially used for knowledge of the native land and his natural richnesses. However, this project was not carried through, but now only forms an interesting testimony to the ideas which penetrated the Polish scholars of the time.

It was well understood that a range of natural history cabinets were essential to the teaching of the science. Thus, one had to organize and arrange them in various schools. The history of the mineralogical cabinet of the University of Krakow begins in 1780, the date of the reorganization of this old school. It is about this same time that the mineralogical cabinet of the School Higher of Wilno was also founded. There was a collection of minerals formed in the Medical School in Grodno by Stanislas-Auguste.

There were also several important private mineralogical cabinets. The collection of the Princess Anna Paulina Jablonowska [1728-1800], in Siemiatycze, was by far the richest. The princess was a rare naturalist in her time. She was well versed in science, and her fluent knowledge of Latin, French and German, opened the study of the world's literature to her. Her multiple voyages to France, Spain, Switzerland, Italy and Holland allowed her to examine first hand many collections and mineralogists. Her predilection for natural history developed early in her life. It was expressed in the vast collections she was to devote the remainder of her life to building. She would, for example, not hesitate to purchase an entire collection, when only a few specimens had drawn her attention. A first hand account of her large cabinet is found in the work of

Jean Bernoulli, *Reisen durch Brandenburg, Pommern, Preussen, Curland, Russland und Pohlen* (Leipzig 1780). According to this description, the cabinet was already in 1778 of considerable size. Later, it occupied five large rooms in the family estate of Siemiatycze in Podlasie. It is said, one of the rooms contained "the ores in natural and artificial form and all matters coming from the interior of the ground." Visiting in Siemiatycze during his voyage from Warsaw to Grodno in 1794, Stanislas-Auguste visited the cabinet. He spent three days with it and part of the night. This is an example of the extent of the collection. One can suppose that this cabinet belonged to the most splendid collections of natural history in Europe of the time. Ultimately, it was sold to the Emperor Alexandre I for the price of 50,000 ducats by the heirs to the princess, who died on 3 March 1800. It is said that this vast sum covered only a part of the actual cost in building the cabinet.

The transitory existence of the University of Warsaw, founded in 1816, shines in the field of mineralogy only by the organization of a mineralogical cabinet. In 1830, it contained 13,677 specimens of the rocks and minerals. By a rare set of events, the city of Warsaw, exposed to so many political upheavals, still contains this cabinet that survives until today. It belongs to the small number of the old scientific institutions of the city that still survive.

It is also to Ignacy Jakowicki [1797-1847] that the first systematic "Description of the Mineralogical abinet of the University of Wilno", preceded by a short historical introduction was written. It was published in Wilno in 1836, at a time when the University had already been closed for several years. This cabinet was definitively supplemented by the purchase of the mineralogical collection of Symonowicz. This contained approximately 20,000 different minerals, of which 400 were singularly valuable. Symonowicz had devoted almost his entire life to the collections formation. At the beginning of 1824, after long negotiations, the University bought this rich collection, including the science library, for 12,250 roubles.

The mineralogical cabinet of the University of Warsaw was reorganized in 1830. The collection of Balthasar Hacquet [1739-1815], bought in 1810 by Duke Frédéric-Auguste, of Warsaw, for the price of 2500 Dutch gold ducats, offered then to the University, was the foundation of this cabinet. This collection contained 4,078 specimens and it was increased further by Michel Soltyk, who purchased from Breithaupt a collection bought in Freiberg in 1820, and another collection of rocks and minerals sold by Lill, Director of the Mines of Wieliczka. Other gifts and acquisitions considerablly enlarged the collection, as is shown by the catalog prepared in 1830 by Zejszner.

Among the mineralogical collections which were formed for the period considered, most significant is that of Pusch, containing mostly minerals that one found with in Polish territory. It was bought in 1833, for the price of 6000 zloty, by the Public Commission of the Instruction, which incorporated it into the mineralogical cabinet of the University of Warsaw. Its remenants are currently in the geological Institute of the University. A list of minerals of this collection (2,551 specimens) was given by Józef Marian Morozewicz [1865-1941] in his Polish translation of Tschermak's minerlogical textbook, *Podręcznik Mineralogii* (1st ed., Warsaw, 1900). This collection was also used initially as an illustration of the traditional work of Pusch, *Geognoslische Beschreibung Polens*. It constitutes at the same time one of the primary sources essential to the preparation of a general Mineralogy of Poland.

Finally, the history of mineralogical collections prior to World War I should be noted. The very rich collection of the Company of the Friends of Sciences in Poznan was founded especially thanks to the zeal of Franciszek Chlapowski [1847-1923], who devoted the work of all his life to awaken in Poland a more intense interest for the natural sciences and work on the physiography of the country. However, the most valuable mineralogical collection that was built during this time, was that of Tytus Chalubinski [1820-1889]. Its catalogue included 3,000 numbers, of which many were composed from many specimens. Jurkiewicz, himself a collector of good taste, said that, among

the European private collections that he had known, few were to be considered to be higher than that of Chalubinski especially with regard to the beauty and scarcity of the specimens. A private amateur, Chalubinski devoted long years and enormous expense to building his collection. His collection became after its death the property of the Polytechnic School, founded in Warsaw a few years later. But the young Polish students could not profit from it for a long time. During World War I, about two thirds of the collection was transported to Russia. Less than a thousand specimens remained, with the loss concerning the most beautiful or most valuable.

Topographical Studies

1928 F. Slavík and L.J. Spencer., "Place names of mineral localities in central Europe," *Mineralogical Magazine*, **21** (1928), p. 441-479. [Alphabetical index of all the place-names in twelve languages.].
1936 A. Laszkiewicz., *Mineralogia*. Warszawa, 1936. 216 p.
1978 Stefan Kozlowski., *Surowce mineralne województwa olsztynskiego praca zbiorowa*. Warszawa, Wydawn. Geologiczne, 1978. 242 p., one plate, illus., colored map. [Mines and mineral resources of Poland.].
2000 Anonymous., *Mineral resources of Poland*. Warsaw, Polish Geological Institute, 2000. 96 p., illus.

Carpathian Mountains

1963 E.O. Lazarenko, E.K. Baryshnikov, and O.A. Maly-Gina., *Mineralogiya Zakarpatia*. Lvov, 1963.
1986 I. Gucwa., *Minerals of the Polish Carpathians*. Warsaw, Wydawn. Geol., 1986. 148 p. [In Polish.].
2002 Sándor Szakáll, ed., *Minerals of the Carpathians*. Prague, Granit, 2002. 479, [1] p., illus. [A topographical study, with considerable historical information, on the minerals of the Carpathian Mountains in central Europe.].

Silesia

1863 H. Fiedler., *Die Mineralien Schlesiens mit Berücksichtigung der Angrenzenden Lander*. Breslau, 1863. 106 p.
1888 H. Traube., *Die Minerale Schlesiens*. Breslau, J.U. Kern, 1888. 286 p.

### 11.2.6.50 Russia (Россия)[1257]

Russia is a vast and diverse country that stretches from the north Atlantic in the west to the Pacific coast in the east, and from the polar deserts of the Arctic to the extra tropical deserts of central Asia and the subtropics of the Transcaucasia. Landscapes in this huge expanse range from grass lands and plains, to forests, glaciers and high mountains, and they show almost the complete range of natural environments found on earth, except for the tropics. For this reason, unlike their European colleagues, Russian explorers rarely left their own country. They were also further isolated by the adoption in the Russian language of the Cyrillic alphabet that is based in part on the Greek characters of ancient times. Straddling the two continents of Europe and Asia, Russia has a unique character that marked its scientific development.

Russian mineralogy holds a significant place with in the science because the country possesses vast mineral riches. The Russian scientists who studied the mineral deposits had an influential effect on the development of mineralogical science as a whole. Their remarkable mineral studies helped to establish general principles with in the science, but it began long before scientific studies were contemplated.

Already in the earliest times, the natural resources of the Altai, the Urals and other locations in the steps of Asia were developed. Primitive mining of copper ores occurred among the many nomadic tribes of the region. Implements, such as dishes and cups, and other tools made of bronze and copper have been found in the earliest tombs. Early evidence of mining has also been discovered. In the Urals and Siberia these early developments frequently helped direct modern mineral explorations.[1258]

Knowledge of Russian minerals carried through to historical times with perhaps the earliest record occurring in the writings

[1257] Further historical information may be found in: Feofan Dmitrievich Bubleinikov., Геологисческие поиски в Росси [Geologischeskie poiski v Rossi]. Moscow, Gosudarstvennoe nauchno-tekhnicheskoe izdatel'stvo literatury po geologii i okhrane nedr., 1956. 251 p., illus. [A history of mineral prospecting and geological research in prerevolutionary Russia.] • Nikolai Aleksandrovich Figurovskii, ed., История естествознания в России [Istoriia estestvoznaniia v Rossii]. Pod red. N.A. Figurovskogo (glav. redaktor) V.P. Zubova, S.R. Mikulinskogo. Moskva, Izd-vo Akademii nauk SSSR, 1957-62. 3 vols. [Long and detailed telling of natural history studies in Russia.] • Dmitri Pavlovitch Grigorev and I.I. Shafranovskii, Выдаиущиесиа русские минералоги [Vydaiushchiesia russkie mineralogi]. Moskva, Izd-vo Akademii nauk SSSR, 1949. 272, [3] p., illus., portraits. [This work on outstanding Russian mineralogists contains a valuable history and bibliography of mineralogy in Russia.]

[1258] Aleksandr Vasil'evich Khabakov., Очерки по истории геолого-разведочных знании в России [Ocherki po istorii geologo-razvedochnykh znanii v Rossii] (materialy dlia istorii geologii). Moskva, Izd-vo Moskovskogo obshchestva ispytatelei prirody, 1950, p. 27. [Description of the history of geological surveys in Russia.]

of the Roman naturalist Pliny the Elder who mentioned in his *Histoire Naturalis* the scythian smaragds (i.e., emeralds).

Iron was recovered in Russia from an early date. Bog ore was easily identified and worked from surface deposits with hand tools. Bog is a reddish-brown colored iron mineralization, easily identified in the northeastern portions of European Russia, where only practical experience was recognized to locate deposits. In Byelorussia in the earliest population centers the foundations of primitive furnaces for smelting iron have been excavated and iron slag has been recovered. The Slavic tribes of the 9th century manufactured steel coins, swords, and spears, and smelted not only enough iron to meet their direct needs but also enough to exchange for furs from tribes in the Urals and Siberia.[1259]

In the 13th and 14th centuries, around present day Kiev and Novgorod a different type of iron ore were exploited. This required a more refined knowledge of the earth and even an acquaintance with the iron containing minerals. The search for mineral pigments also helped in the exploration for new sources of iron. Sometimes the presence of pigments like ochre or umber would indicate the presence of iron ores deeper in the earth. The use of coloring in pottery craft shows a widespread search and use of mineral pigments through out the region.

Salt was another important mineral of economic value in the earliest periods. As early as the 12th century, salt obtained from deposits in southwestern Russia near the Carpathian mountains was being taxed by the government. In addition to the naturally occurring deposits, salt was obtained in a primitive way by evaporating pools of brine. This led to the development of some understanding of hydrogeology and knowledge about the location of underground springs and other sources of water.

Various stones used in large scale construction were also exploited. Important tombs dating from the 9th century onwards were constructed of quarried limestone, and in the case of Prince Mistaislav (died 1178) immense blocks of labroradite. Prophyllitic schists, white marble, massive malachite, among other stones were used to create cornices and other decorative features.[1260]

Clearly, some extensive practical knowledge of minerals existed with in early Russia, but very little of this geological and mineralogical knowledge were recorded in the extant written documents of the time. In fact most descriptions related to minerals or gems recount the legendary information about the miraculous properties of the stones, which is sometimes interwoven with biblical symbolism, just as are stories about various animals and plants. This literature was intensely spread by the Russian church.

Beginning in the 15th century and extending through the 17th, the growth and formation of the centralized Russian government considerably contributed to the exploitation of the most important minerals like salt, iron, copper ores, and construction stones grew considerably. In addition, explorations for new sources as well as searches for precious metals and stones became important. Large amounts of iron and steel were needed to cast bells used to adorn the many new churches and palaces built in the region. The military applications were also large as bronze and iron were needed in the manufacture of swords and canon. To aid in the exploration, the clergy of the church was tapped. Any indications of mineral deposits in the vicinity of a the growing network of monasteries and churches was to be reported back to the central authorities. This led to the discovery of many new mineral sources for the Russian government.

Exploration occurred through out the land, and new applications were found for the materials recovered. At the base of one monastery a deposit of large mica crystals was discovered. Because of its crystal structure large transparent sheets of mica could be cleaved perpendicular to the long axis of the crystal. These sheets are transparent and were easily substituted as window panes in urban dwellings or as fire resistant chimneys in the

[1259] ???????

[1260] ???????



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oil lamps of the day. Beginning in the 16th century significant quantities of this mica was shipped abroad, and the Russia mica became widely known as "Muscovite" glass, a term still used to identify this variety of phlogopite mica.

Also in the 16th century an explosion of exploration paralleled the growth of settlements as they pushed to the base of the Ural Mountains. Merchants, tradesmen, craftsmen, framers, and the destitute all began to examine the land for new underground riches. Frequently, owners of the land initiated the search for new minerals. The Stroganov's who owned large tracts in the west developed large salt works and other mining and milling operations. They obtained the Tsar's permission to recover iron, copper, tin, lead, sulfur, etc., and it was this family over several generations that supplied much of the raw material used to create the weapons used during the numerous Russian conflicts of the time.

At the start of the 17th century, as the eastern borders of Russia were pushed out, vast and rich new mineral deposits of copper and iron were discovered in what is present day Siberia. These ores were exploited by the use of underground mining techniques. As the century wore on, the eastern border continued to expand toward the Pacific and more rich veins of silver, gold, precious stones, as well as the industrial minerals were found. The government began to encourage discoveries to be reported, offering 50,000 Rubies to the discoverers.[1261] However, to this time little effort was spent attempting to create a theoretical or even practical explanation to help discover new mineralization in Russia. In fact, the few records that have been survived from this time indicate the barest of statistical information about the minerals and metals recovered, and the quantity produced. There were no texts devoted to mineral exploration in Russia. In fact, the primary works used seem to have been imported European books on mining such as Agricola, Ercker and Gesner; however, these were not deemed worthy enough to translate into Russian! Thus the foundation was set for important theoretical and practical discoveries by Russian in geology and mineralogy.

[1261] ??????

### 11.2.6.50.1 Russia (18th Century)

In Russia at the beginning of the 18th century the elements for an explosion of scientific research was set. There was a strong demand for an efficient mining method to recover material from the deposits already discovered, and a desire to refine the material in the most cost effective way. This pressure led to the gradual geological study of the now quite vast Russian territory. In 1718, among the first to record descriptions of the mines and metal works of the Urals comes from V.N. Tatishchev,[1262] who developed both mining and agricultural resources in the Urals. He is also credited with founding an early school to train mine employees in the techniques and procedures of their jobs that had a large positive effect on increased metal production.[1263]

The successes of Russian mining and mineral resources generally are vividly reflected in the words of Peter the Great, who in an edict of 1719 confidently wrote: "Our Russian state is blessed before all others with the required metals and minerals". It was a time when in connection with the strengthening of industry and military science, mining receives further rapid development. The smelting of metals from ores increased enormously. In Russia, predominantly in the Urals, there are discovered and opened large numbers of new ore mines. Finally, industrial and military pressures caused the land to be investigated more systematically by scientific methods. The initiator of this stage of Russian mineralogy is the brilliant Mikail Vasilievich Lomonosov.[1264] In his book,

[1262] V.N. Tatishchev [1686-1750] ...

[ ]
[ Biography Needed ]
[ ]

[1263] G.A. Smirnov., "[Role of V.N. Tatistchev in the development of mining and geological prospecting in the Urals]" (pp. 132-154) in: *Ocherki po Istorii Geologicheskikh Znanii*, **5** (1956). Moscow, Akademii Nauk SSSR. [In Russian]

[1264] Mikail Vasilievich Lomonosov [1711-1765] was the son

*First Basis of Metallurgy or Ore Matters*, and in his important articles *About the Layers of Terrestrial Earth*, and *About the Generation of Metals from the Earth* there is set forth a remarkable collection of statements about the formation of minerals in the context of the observed geological phenomena. Being a deep theorist, Lomonosov was at the same time the most important experimenter. In his laboratory he studied metals, salts and others minerals. In contrast to his contemporaries, this distinguished scientist understood well that "the natural history cannot be learned in the office. It is necessary to visit many very different mines". He inspired Russian miners with his *First Basis of Metallurgy or Ore Matters*, which because it was written in the Russian language was widely used in the field as a practical handbook.

The systematic combination of theory and practice, the thorough study of factual material both in the field and into the laboratory, the deep physical chemistry approach to the observed phenomena are the outstanding features, which Lomonosov attempted to use as the basis of the science about minerals. A relatively early death brought an end to this distinguished scientists labor, but he is regarded as the first of the great mineralogists of Russia. However, Lomonosov perhaps anticipating some views of our time speaks about the importance of intersected ore veins, and for the first time establishes the concept about their relative ages. At the same time his colleague at the Academy Johann Gottlob Lehman,[1265] created fantastic theories, about the veins growing like trees with in the earth and thought that veins were the branches around some enormous trunk, that emanate from the center of the earth. Although Lomonsov did not travel much, his writings set the foundation for an extensive interest in the mineralogical history of the whole of Russia.

**Geographial Expeditions**

During the second-half of the 18th century, the Russian Academy of Sciences with government backing organized and conducted a series of immense expeditions to study European and Asiatic Russia, which gave occasion for foreigners to suggest that no other country was at that time so well studied as Russia. This expeditionary activity makes it possible to call this stage of Russian science as the time of the expeditionary period, which is reflected in the bright imprint it put on the state of mineralogy during the 18th century. Enormous quantities of material were gathered about the ethnography, the fauna, the flora and the mineralogical treasures of the country by the famous academic expeditions in Kamchatka, Urals, Altai, Transbaykal, the Caucasus, and into different regions of European Russia.

Stephan Petrovich Krasheninnikov gives in his *Histoire et Description du Kamtchatka ...* (Amsterdam, Rey, 1743; 2 vols.) a report of a journey made to explore eastern Siberia in 1735-1741, by order of the Russian Imperial Government. The very rare Russian original text was published in St. Petersburg in 1755. It is the first detailed scientific account of Kamchatka and the surrounding islands. It is also one of the earliest printed accounts of Alaska and the Aleutians. Krasheninnikov was Steller's assistant on Bering's second expedition. The third chapter contains an important account of the Kuril Islands and Japanese influence

of a farmer and fisherman, and as a youth he travelled the northern seas. Early on he learned to read and write. In 1730, he traveled by foot to Moscow where he studied ancient languages in the city's academy. In 1736 having shown himself to be one of the best students, he was first sent to the St. Petersburg Academy of Science and then for three years to Marburg University in Germany where he was instructed by the philosopher Christian Wolff [1679-1754]. In 1739, Lomonosov traveled to Freiberg in Saxony to work in the laboratory of Johann Friedrich Henckel. There he became immersed in problems of mineralogy, mining and metallurgica chemistry. He returned to St. Petersburg in 1741. Lomonosov was made an associate professor of physics at the academy in 1742, followed by a professor of chemistry in 1748. From this post, he opened in 1745 the first chemical laboratory in Russia, and in 1758 became director of the geographical department. Through out his carrer at the St. Petersburg Academy, Lomonosov was continuously fighting the imported European scientists to make Russia a true scientific power. His believe was that his homeland was the equal of any country in Europe, but the dominance of foreigners on the committee disregarded his patriotic views.

[1265] Johann Gottlob Lehman [1700-1767] made many notable contributions to geology, metallurgy, chemistry, and mineralogy. He is considered the founder of stratigraphy. He also founded the Freiberg Bergakademie which became famous under the directorship of Werner.

thereon. The fourth chapter deals with "that part of America which lies directly East from Kamchatka" from "notes taken out of Mr. Steller's journal". Notice is made of the mineralization and geological features seen along the journey.

With beginning the 18th century took the scientific research in Russia an enormous upswing. On several expeditions both the interior and the adjacent areas were opened. One of the most famous these expeditions was the large Nordische or second Kamcatka expedition, which took approximately ten years (1733-1743) and under the overhead line of the Danish captain Bering. Participants in this enterprise were also numerous scholars briefly before of the created Academy of Sciences in pc. Petersburg. Since the circle was still extremely small scientifically formed persons at that time in Russia, above all foreigners, under it, ranked not few Germans among it. To the academic group also the chemist Johann Georg Gmelin[1266] and the historian Gerhard Friedrich Mueller belonged to the expedition. Ten years long traveled the two scholars this way and that by Siberia, collected, cartography ores, noted. They were after Daniel G. Messerschmidt, who investigated Siberia between 1720 and 1727, the first scientists, who researched the up to then to a large extent unknown part of the Russian realm approximately systematically. Gmelin wrote its famous *Flora Sibirica* become during and after its journey, a foundation of the Botanik. After Gmelin in the discord of the Academy of Sciences was divorced and a Professur in its hometown had received Tübingen, he wrote his fourth-hasty report on a journey, which appeared in the years 1751/52. In an immense material abundance it described flora and fauna, above all however its numerous meetings with the Siberian Urbevölkerung, whose habits and habits in detail the pietistische representative of the early clearing-up described. A scarce set containing extensive reports of explorations through Russia and Persia, including those of Peter Pallas and J.G. Gmelin. There is, as a result, a significant amount of material on Russian America. Pallas, in the period from 1768 to 1774, explored the region around the Caspian, crossed the Urals, went north to Krasnoyarsk, and covered much of Siberia. Working mostly in the 1730s and 1740s, Gmelin made wide-ranging explorations and botanical examinations of Persia, Siberia, and the area around the Caspian Sea. The largest of the folding maps shows the area around the Ural Mountain range, and the others show the region around the intersection of the Don and Volga rivers, and the Ukraine. The attractive plates mostly show the costumes and dress of the peoples of Central Russia and Persia.

Petr Simon Pallas,[1267] was an eminent botanist, zoologist and geographer, who travelled through southern Russia, the area of the steppes near the Caspian Sea, the northern Caucasus and the Crimea in 1793-94. In his account, which appeared in German in 1799-1801, he desribed the flora and fauna, landscape, geology, mineralogy, local population, and culture. Pallas, of German origin, was a member of the Russian Academy of Sciences and on request of the Russian government explored the lesser-known provinces of the Russian Empire. His travel books opened up Russia to the West and served as a model for eighteenth century travel literature. The plates depict native inhabitants and their dwellings, views, and examples of the flora and fauna encountered. This second French edition was expanded with notes by specialists such as Lamarck on botany and Langles on the eastern languages. First published in German in St. Petersburg in 1771-76, the first French edition appeared 1788-93. 'In 1767 Pallas was invited to work at the St. Petersburg Academy of Sciences. ... During his first years there he studied nature and the

[1266] Johann Georg Gmelin [1709-1755] ...

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[1267] Petr Simon Pallas [1741-1811] was invited by Catherine the Great to work at the Academy of Sciences in St. Petersburg, and consequently had a tremendous influence the development of science in Russia in the 18th century. Pallas was also responsible for establishing the botanical, zoological and geological collections at St. Petersburg. He was one of the most distinguished naturalists of his time.

peoples of the Russian Empire, participating in the "Academic expeditions" of 1768 - 1774. His research as leader of the first Orenberg detachment of the expeditions covered both European Russia and Asia. Pallas and his companions journeyed from St. Petersburg to Moscow; crossed the Volga at Simbirsk ...; and explored the Zhiguli Mountains and the southern Urals, the steppes of western Siberia and the Altay, Lake Baikal, and the mountains of Transbaikalia ... His results were published in "Reise durch verschiedenen Provinzen des russischen Reichs ... (1771 - 1776), which later appeared in Russian ... and in French, English and Italian. Pallas' writings ... enriched natural history by providing massive amounts of empirical data ...'.

Ivan Ivanovich Lepekhin[1268] and Nikolai Alkovlevich Ozeretskovskii,[1269] *Dnevnyi?a? zapiski puteshestvii?a? doktora i Akademii nauk ad"i?u?nkta Ivana Lepekhina po raznym provint?s?ii?a?m Rossiiskago gosudarstva, 1768 i 1769 godu.* (Sanktpeterburg, Pri Imperatorskoi Akademii nauk, 1771-1805; 4 vols.) contains a vast quantity of material collected during their expeditions. The Russian minerals were concentrated in the first natural history museum, established by Peter the Great in 1718 in St. Petersburg, which had been founded to store natural rarities. This Kunstkammer was the nucleus around which grew the splendid modern mineralogical museum of the Academy of Sciences of Russia. At the same time, in competition with the government, members of the upper classes of Russian society begin to become interested in the collecting of mineralogical specimens generally. These amateurs with great enthusiasm gather their collections of minerals, gemstones and fossils.

In connection with the accumulation of abundant research material, the general nature of mineralogical studies in Russia began to change. In addition, intense pressure to recover more minerals increased the number of studies into mineralogy. From with in the 18th century, the history of Russian mineralogy begins a new period where active study of the accumulating facts attempts to bring order to the science. For example, Erik Laxmann[1270] described Siberian lazurite, baikaljte, the new variety of garnet (grossularite), the crystals of wiluite, dark mica from Slyudyanka river (phlogopite) are just a few of the new minerals described.

Exceptional for the impression it produced in its time was the retrieval of a large iron meteorite from near Krasnoyarsk. It was obtained from a local resident by Medeve in 1749 and sent back to the St. Petersburg Academy. There it was chemically analysed by Petr Simon Pallas, who showed that it was made of elemental iron, a metal that at the time was never known to occur as a native element. Pallas' study would later help prove the extraterrestrial origins of meteorites, and his name is commemorated in other meteorites of this type being called "pallasites" in honor of their first scientific investigator.[1271]

### Severgin

The most outstanding representative of this epoch was famous Russian mineralogist and chemist Vasilii Mikhailovich Severgin.[1272]

[1268] Ivan Ivanovich Lepekhin [1740-1802] ...
[ ]
[ Biography Needed ]
[ ]

[1269] Nikolai Alkovlevich Ozeretskovskii [1750-1827] ...
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[ Biography Needed ]
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[1270] Erik Laxmann [1737-1796] ...
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[ Biography Needed ]
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[1271] John G. Burke, *Cosmic debris*, 1986: p. 29-30.

[1272] Vasilii Mikhailovich Severgin [1765-1826] was admitted to the private Gymnasium of the St. Petersburg Academy of Sciences in 1776. He matriculated at the Academy's University in 1784 choosing mineralogy as his speciality. In 1785, he travelled to Göttingen to study under J.F. Gmelin. There he became involved in the controversy between the neptunists and the plutonists. Upon returning to St. Petersburg in 1789, he was appointed an adjunct in the department of mineralogy of the Academy of Science. In that post, Severgin began a long and influenial career in the teaching of science in Russia generally and especially mineralogy. He examined minerals from a chemical basis which followed Lavorsier's theories. This was sustained by his numerous publications, which appeared through out his lifetime. Besides Severgin's mineralogical writings, he also published translations of European works on metallurgy, chemistry and physics. In 1804, he founded the *Teknologichesky Zhurnal* (Technological Journal), which he also edited until 1824. Severgin was also a founding

In his *First Bases of Mineralogy*, *Mineralogical Dictionary* and other chief works of Severgin he gave thorough summaries of the accumulated information about mineralogical material. He paid special attention in his works to domestic minerals. Carrying out Lomonosov's vision, Severgin brought out in 1809 *The Experience of Mineralogical Descriptive Geography of the Russian State*, which was the first topographical summary for Russia. It presents a dry enumeration of mineralogical and geographical names and shows nothing remarkable from the labors of Severgin. At the end of the 18th century however, mineralogical science was entering a new period of scientific development. No longer was it a simple accumulation and rearranging of facts, but a new theoretical undercurrent was building, and the most important Russian representative of this new approach was Severgin. He introduced a new mineralogical system and focuses his attention on the theoretical mineralogy. He mentions the paragensis of minerals (i.e. the characteristic associations between minerals), using the Russian term for "contiguity". His mineralogical work was the exceptional research in Russia of his time. Severgin always tried to introduce the newest theories into his writings, and even in his old age after learning of Haüy's new theory of the structure of crystals, he becomes an avid supporter. His *Detailed Mineralogical Dictionary* of 1807 begins with an account of this theory. The works of Severgin on mineralogy and chemistry are tightly connected with the development of domestic industry. He was untiring in his promotion of the need to study the Russian mineral riches, showing their value in industry and technology. On the whole, Severgin appears in the history of Russian mineralogy as the outstanding worker in Russia of the late 18th and early 19th centuries; however, there were others who made important mineralogical contributions during this epoch.

Andrei Andreevich Nartova,[1273] the Vice President of Berg-board, chief commander [Gorny] school who edited a *Slovar Mineralogicheskii* [Mineralogical Dictionary] (St. Petersburg, 1790).

Fedor Petrovych Moiseienko,[1274] a talented Ukrainian mineralogist, who died young, authored *Mineralogische Abhandlung von dem Zinnsteine* (Leipzig, 1779), a work describing the tin containing mineral cassiterite.

Apollos Apollosovich Musina-Pushkin,[1275] the wrote on the mineralogy of region of Georgia.

T.E. Lowitz,[1276] an untiring analyst of minerals and a researcher into crystallography.

An introductory work, Andrei Mikhailovich Teriaev's,[1277] *Kratkoe Razsuzhdenie o Mineralogii* [Short Mineralogical Introduction] (1796) gives a presentation of mineralogical science, providing information on the latest discoveries and emphasizing economic aspects, and his *Istorii Mineralogii* [History of Mineralogy] (1819) records for the first time in book form the history of mineralogy.

In the *Mineralogische Reisen in Siberien*

member of the Mineralogical Society of St. Petersburg.

[1273] Andrei Andreevich Nartova [1737-1813] was educated in St. Petersburg at the military academy, after graduating he went into the artillery. In the 1860's he took up scientific studies, becoming an important translator of foreign works into Russian. He was one of the founders of the important Free Economic Society, serving as it president from 1797 to 1813. He also contributed to the development of mining and mineral resources in Russia, being appointed to the Board of Mining at the Mining Institute in St. Petersburg in 1774. From 1778 to 1783 he took on the role of director of the Institute.

[1274] Fedor Petrovych Moiseienko [1754-1781] became a member of the Russian Academy of Sciences in 1779.

[1275] Apollos Apollosovich Musina-Pushkin [1760-1805] studied the metals of the platinum group from a chemical point of view, leading to the creation of several new compounds. He was also successful in isolating malleable platinum by heat treatment with mercury. He was appointed Vice President of the national Board of Mining, and in that role he organized expeditions to study the mineral resources of the Caucasus and Transcaucasia, which contributed to the development of mining operations there. From 1799 to 1805 while heading another expedition to the Transcaucasia, where he died suddenly.

[1276] T.E. Lowitz [1757-1804] ...

[ ]
[ Biography Needed ]
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[1277] Andrei Mikhailovich Teriaev [1767-1827], from 1789, was a teacher of natural sciences in St. Petersburg. In 1804, he was appointed professor of the pedagogical Institute, and in 1809 professor of medicine at the Academy of St. Petersburg. He authored books on mineralogy, botany, zoology, and made improvements to the teaching of these subjects.

*vom Jahren 1783-1796* (St. Petersburg, 1798-1801; 3 vols.), Benedict Franz Johann Hermann[1278] gave a detailed description of the mines, minerals, plants and animals of the Urals and Siberia.

### Moscow University & St. Petersburg Mining Institute

Enormous value in the history of the Russian mineral science happened with the founding of Moscow University in 1755,[1279] and the Mining Institute founded in 1773,[1280] which was established to help meet the needs of the rapidly developing Russian mining industry. Established in St. Petersburg, the Mining Institute, is a landmark in the development of Russian mineralogy. The history of mineralogy at the mining institute is to a considerable degree a mirror of the Russian mineralogy generally. Using the Freiberg Bergakadamie as a model, the Mining Institute was founded in St. Petersburg in 1773 and directed by Michael Fedorovic Sojmonov.[1281] This institution, later renamed to a School for Mining Cadets (1804) and for Mining Engineers (1834), was one of the most important centers of geological research in Russia during the eighteenth and nineteenth centuries (Guntau, "Geologische Institutionen," pp. 230-231). From its founding, mineralogy was part of the basic training given to any students enrolled at the Institute, and in fact at the earliest times the only study available in geology. Mineralogy was used to give students an accurate foundation in learning to identify species of ores and their potential value. General geographical and historical knowledge of minerals was taught, as well as introductions to mining and metallurgical operations. It was a practical technical education intended to train its students in mineral resource identification and exploitation. A large mineral collection was also started at the Mining Institute to help train the students. It consisted of both domestic and foreign minerals and remains today one of the best mineralogical collections in the world.

### 11.2.6.50.2 Russia (19th Century)

In the 19th century the schools of mineralogy at the Mining Institute of St. Petersburg were directed by practical men. An good reputation was enjoyed at that time by Dmitrii Ivanovich Sokolov,[1282] who read for 33 years the courses in geological sciences at the Mining Institute. He also taught mineralogy at the St. Petersburg University, which was opened in 1819. He also taught the first course of crystallography at any Russian school. Sokolov was famous as talented speaker, and his public lectures were always well attended. Exceptional for the time, he also opened them to interested women. Sokolov's *Rukovodstvo k*

[1278] Benedict Franz Johann Hermann [1755-1815] who was of Austrian origin, moved in 1782 to Russia, where he became involved with the administration of the mineral resources of that country. He made many trips through out the Urals and Siberia gathering extensive material on the mineralogy, metallurgical techniques, history of mining, ore reserves, etc. of the region. He also did extensive studies on the botany. He formulated for government plans on improving efficiency, and recommended a national census be under taken. He was elected a member of Berlin-Brandenburgischen Akademie der Wissenschaften.

[1279] Demian I. Gordeev., Историја геологицескич наук в Моковском Университете [Istorija geologiceskich nauk v Mokovskom Universitete]. (K 258 letijuso dnja rozdenija M.V. Lomonosova 1711-1961). Moskva, 1962. 352 p., portraits, illus. [History of geological science studies at Moscow University.]

[1280] D.P. Grigor'ev., Минералогия в Горном Институте за 175 лет. [Mineralogiia v Gornom Institute za 175 let]., *Zapiski Vsesoiuznogo Mineralogicheskogo Obshchestva*, **77** (1948), no. 3, 177-184, 2 plates. [Outlines the 175 year history of the Mining Institute of St. Petersburg, Russia.]

[1281] Michael Fedorovic Sojmonov [1730-1804] ...

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[ Biography Needed ]
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[1282] Dmitrii Ivanovich Sokolov [1788-1852] was sent to the preparatory class of the St. Petersburg Mining School, from which he graduated in 1805. After graduation, he worked for a time as an assayer in the Academy's laboratory, and then he began giving lectures first in metallurgy and assaying and later in geognosy and mining. Soon, a position as a permenant instructor of the Academy was offered and accepted. Sokolov retained the job until 1841. From 1822 until 1844, he also held a professorship at the University of St. Petersburg. He was a founder and the first editor of the *Gornyi Zhurnal* (Mining Journal), which was one of the first specialized periodicals published in Russia. The principal geographical work Sokolov is remembered for relates to grouping the red stratigraphic beds of the Trans–Volga Region into its own independent system, which was named "Permian" in 1841 by Sir Roderick Murchison [1792–1871]. Sokolov was a founding member of the St. Petersburg Mineralogical Society in 1817, and he was also elected to the Russian Academy of Science in 1839.

*Mineralogii* [Handbook of Mineralogy] (1832) and its supplement (1838) were for a long time the model of for Russian mineralogical textbooks. He includes valuable information about Russian minerals and mineral resources, especially vein structures. In his descriptions Sokolov was characteristic of the period in his qualitative, descriptive mineralogy. However, in comparison with many other works of that time, his clear descriptions present an essential step forward. In particular, Sokolov introduced into the mineralogy new views on the chemistry of minerals.

At Moscow University Aleksei Leont'evich Lovetskii[1283] was a typical representative of the descriptive mineralogy taught at the time. Students of the time were required to remember long lists about the characteristics of minerals, that was not reinforced with numerical data. Understandably, for the mineralogical students of this time, the classes about minerals were considered among the dullest and most difficult of disciplines. Lovetskogo book, *Nachal'nye Osnovaniia Mineralogii* [First Foundation of Mineralogy] (1832) reflects this dry recitation of facts.

### St. Petersburg Mineralogical Society

Moscow went into a major phase of construction after the victorious end of the Napoleonic war of 1812. The erection of these buildings led to the intensive investigation of building materials such as different marbles, limestones, granite, porphyries, and to intensive searches for ornamental building stones like malachite, lazurite, nephritis, and especially attractive marbles and jasper. Stone work during this time achieved new heights with craftsman creating magnificent mosaics for the palaces and government buildings of the period. The famous malachite room was also constructed during this time. In this nurturing environment, there appeared in Russia a close knit group of amateur mineralogists, which eventually led to the formation on January 19th, 1817 of the St. Petersburg Mineralogical Society.[1284] This society would leave an indelible track in the history of the development of geological and mineralogical science in Russia. The societies activities immediately enveloped a circle of questions that it would guide its direction, but its principal object was to examine all aspects of the science, including inorganic nature, identifying and testing the properties of minerals, and relationship of minerals to geology, and to promote this knowledge to others. To disperse any discoveries the society would make, they began publishing the transactions of the society *XXXXXXXXX* that is by far the greatest contribution to the scientific knowledge of Russia, and the world of geological and mineralogical science generally. This important mineralogical journal is still published 180 years after its founding.

Over the long years of the societies existence many hundreds of young scientists developed excellent scientific material. The geological studies of society delivered many valuable insights into the explanation of the geological structure of Russia and on the development of its mineral riches. Contained in the imposing number the society's transaction volumes there is an abundance of the cumulative data on mineralogy, crystallography, petrography, geology, paleontology, and studies of the like, that helped to adorn these sciences in the world generally.

The Mineralogical Society was always closely connected to the Mining Institute of St. Petersburg, and it is possible through out the 19th centuries to the revolution to divide the time into the periods of the particular leaders of the time. Thus the time may be divided into the schools of Koksharov, Eremeev, Fedorov, Boldyrev, and Smirnov.

A renewed interest in mineralogical expe-

[1283] Aleksei Leont'evich Lovetskii [1787-1840] graduated with an medical degree in 1812. In 1826 he was appointed professor of surgery at the Academy of Science. In 1834, he also became a professor of natural history at Moscow University. He authored works on questions of zoology, mineralogy, economy, physiology and pathology. He was also an early investigator of infectious diseases of humans, and held the view that they were transmitted by parasites in the body.

[1284] S.P. Solo'ev., Всесоюзное минералогичецкое общество и его роль в развитии геологических наук (1817-1967). [Vseso?uznoe mineralogicheskoe obshchestvo i ego rol' v razvitii geologicheskikh nauk (1817-1967)]. Leningrad, "Nauka," 1967. [1]-232 p., illus. [History of the St. Petersburg Mineralogical Society from its founding in 1817 to 1967. An updated second edition was published in 1990.]

ditions began in the 19th century. These expeditions brought forth an abundance of new minerals, especially from the Ilmenskii mountains. The journeys at this time are conducted in parallel with intensive laboratory work on a study of the Russian minerals recovered. For example, at the invitation of the Russian Czar, Nicholas I [1796-1855], three German scientists undertook a scientific expedition into the remote Siberian reaches of the Russian Empire in 1837. Their travels covered nearly 16,000 kilometers, reaching as far east as the Altai Mountains, just north of the Mongolian border. Gustav Rose,[1285] the mineralogical expert of the group, recorded the account of their investigations that includes accounts of the gem deposits such as the Mursinka pegmatites, the Nizhne-Tagilsk district, the Schaitansk Tourmaline deposit, the Takovaja Emerald deposit (including discussion of the famous Chrysoberyl deposits), the Gumeschevsk Copper mine, the Miask deposits, and many others. Other researchers described many new mineral forms and varieties. In 1839 the mining engineer I.R. Lisenko[1286] described the new minerals from the Urals: xanthophyllite and hydrargillite. Professor of the mining and technological studies at the Institute Herman Ivanovich Hess,[1287] the author of the well-known law of thermochemistry, he was also mineralogist. He described the new minerals: hydroboracite, worthite, volborthite, and uvarovite. In 1842, the variety of Chrysoberyl called "alexandrite" was formerly announced in the transactions of the Mineralogical Society. To the Moscow chemist and mineralogist R. Herman[1288] we are obliged for the descriptions of a whole series of new minerals: chiolite, Prophyllitic, tagilite, dihydrite and other minerals. Furthermore, this scientist described the mineral varieties: ratofkite, strogonovite, and volknerite.

The chemists gave the first analyses of many Russian minerals. From Peter Ivanovich Evreinov[1289] came chemical composition of wiluite and leuchtenbergite, and N.A. Ivanov[1290] who provided the many chemical analyses contained in Koksharov's *The Materials*. The first analysis of paligorskite was executed by Dimitrii Mendeleev,[1291]

[1285] Gustav Rose [1798-1873] was born into a family with a strong tradition in science. His grandfather, Valentin Rose the elder, invented the low-melting alloy still called Rose's metal. His father, Valentine the younger made original contributions to procedures in inorganic chemical analysis, and his brother Heinrich was a famous chemist in his own right. In 1815, at the age of only seventeen, Gustav with his brothers fought in the campaign against Napoleon. The following year, he became an apprentice at a mine in Silesia, but left due to illness. He graduated from the University of Berlin in 1820, and traveled to Stockholm to work in the laboratory of Berzelius. Returning to Germany in 1823, he began his lifetime career at the University of Berlin becoming professor extraordinary in 1826 and professor ordinary in 1839. In 1856, Rose succeeded Weiss as director of the Royal Mineralogical Museum. Together with F.H.A. von Humboldt, E. Mitscherlich and others, he founded in 1848 the Deutsche Geologische Gesellschaft. The mineral "Roselite" was named in his honor by A. Lévy in 1824.

[1286] I.R. Lisenko ...

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[1287] Herman Ivanovich Hess [1802-1850] was born in Geneva, Switzerland, but was taken to St. Petersburg at the age of three years when his family moved. He graduated from Tartu University with a medical degree. He worked for a time under Berzelius in Stockholm. On his return to Russia, he became a professor of chemistry at the Mining Institute of St. Petersburg. In 1831 and 1849, a textbook on chemistry that he authored was published to wide appeal. The mineral hessite was named in his honor in 1843.

[1288] R. Herman [1805-1879] ...

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[ Biography Needed ]
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[1289] Peter Ivanovich Evreinov [1812-1849] was an instructor of chemistry at the Mining Institute in St. Petersburg, as well as the manager of the department laboratory. In 1843 he published papers outlining the use of cyanide in the extraction of gold from ore, which is today the principal method of metal recovery through out the world's mines.

[1290] N.A. Ivanov [????-????] ...

[ ]
[ Biography Needed ]
[ ]

[1291] Dimitrii Mendeleev [1834-1907] was from 1850 a student at the Pedagogical Institute of St. Petersburg. In 1856 he graduated with a degree in chemistry from the University of St. Petersburg, after which he traveled through out Germany and France working in other chemical laboratories. On his return to Russian in 1863, he was appointed professor of chemistry at the University of St. Petersburg, a position he held until 1890. Using only the 63 elements known at the time, he developed a periodic system of chemical elements according to their atomic weights from 1869 to 1871, thereby bringing order to the list of chemical elements. From this list, Mendeleyev was able to correctly predict the properties of several unknown elements. He discovered the elements gallium (1875), scandium (1879),

who is best known as the originator of the periodic chart of the elements. This remarkable Russian chemist also prepared analyses of orthite and pyroxene from Finland (1854-1856), which led to his thesis on the connection between crystalline form and chemical composition in isomorphic minerals, that was printed in the "Mountain Periodical" and concerns deep questions connected with crystallography and mineralogy.[1292] A change was taking place in mineralogy at this time. The accumulating knowledge of the chemistry of Russian minerals is no longer simply plotted in the old qualitative-descriptive mineralogy, but now are falling with in new theoretical frameworks of crystallographic constants, such as those proposed by Adolph Theodor Kupfer,[1293] among others. There is a new holistic approach to minerals, that would preshadow the next period of mineralogy that would be ornamented with a precise descriptive mineralogy.

### Koksharov

The beginning of this period is started by that reanimation in the development of industry and transportation of Russia, which was characteristic of the early 18th century. This period is noted by the remarkable successes in Russian science generally, and most of all in the natural sciences. New requirements for the mineral ores forced technology and theory to improve in their approach to the study of ores and their corresponding minerals. The previous purely qualitative descriptions proved to be insufficient for this new time.

The ancestor of precise descriptive mineralogy was the mining engineer Nicolai Ivanovich von Koksharov.[1294] In his works the ancient method of the verbal description of minerals finally yielded their place to a more mathematically precise crystallographic study. Mineral science today is obliged to this blossoming of Russian mineralogy and crystallography. Through out his entire life Koksharov worked in one field, being almost completely occupied by the crystallography and description of Russian minerals. The cumulative results of his studies in this field are summarized in monumental 11 volume *Materials for the Mineralogy of Russia*, that has been since its publication the classic and unsurpassed study of Russian minerals. Koksharov's precise crystallographic studies built a solid foundation on which the furtherance of mineral science was extended. Because of his position as an important instructor in mineralogy at the Mining Institute, the precise methods used by Koksharov became simultaneously the methods of the school. Thus the strictest accuracy of descriptions, deep respect for actual data, repeatedly checked results of measurements characterize the work of this period.

### Eremeev

A student and colleague of Koksharov was Pavel Vladimirovich Eremeev.[1295] As an instructor at the Mining Institute, Eremeev

and germanium (1886).

[1292] isomorphism in connection with other ratios of crystalline form to the composition. 1856

[1293] Adolph Theodor Kupfer [1799-1865] taught chemistry and physics at the Univesity in Kazan. He was a member of the Academy in St. Petersburg and director there of the magnetic–meteorological Institute.

[1294] Nicolai Ivanovich von Koksharov [1818-1892] was born into a family of mine engineers. Hence he was educated at St. Petersburg Military School of Mines (today the St. Petersburg Mining Institute), 1830-40. Being the outstanding student, he selected to accompany Murchison and De Verneuil, and afterwards De Keyserling in their extensive geological surveys of the Russian empire, 1840-41. From these travels Koksharov became interested in mineralogy, and most particularly Russian species. Traveling extensively throughout Europe, he made the acquaintance of many distinguished mineralogists, notably C.S. Weiss and G. Rose in Germany and W.H. Miller in England. Koksharov had a distinguished career, becoming director of the Imperial Mineralogical Society of St. Petersburg, 1865-92 and director of the St. Petersburg Mining Institute of Mines, 1872-81. He also held membership in some sixty Russian and foreign scientific societies. Koksharov's private collection of minerals consisting of about 3,250 specimens and particularly rich in Siberian species, was purchased by the British Museum of Natural History in 1865.

[1295] Pavel Vladimirovich Eremeev [1830-1899] in 1851 graduated from the Mining Institute in St. Petersburg, and worked in the Russian mining industry until 1866 when he returned to the Institute as professor of mineralogy and crystallography, a post he held until 1896. He was a member of the St. Petersburg Mineralogical Society, and his numerous contributions to the society's journal show his deep interest in Russian minerals. His articles are punctuated with precise notes on the crystallography, mineral associations, paragensis, etc. of the described species. He also made special studies of Russian pseudomorphs.

taught mineralogy for 40 years, and he promoted the systematic study of crystalline forms of Russian minerals. In contrast to Koksharov, however, Eremeev is not limited to the study of the rarely encountered crystals, but emphasizes describing even the most common Russian minerals and investigating their formations in the field. Eremeev also recommends the close study of pseudomorphic minerals.

In comparison with the two exceptional figures in Russian descriptive mineralogy Koksharov and Eremeev, their contemporary mineralogists seem somewhat wanting. There are a few exceptions, however, a professor at the St. Petersburg University and the Forest Institute Mikhail Vasil'evich Erofeev[1296] authored an original studies on the structure of crystals. He prepared a monograph on the crystallographic and crystalloptical study of tourmalines in 1870, in which Yerofey comes very close to describing crystalline substances in a manner close to modern structural theories. Erofeev developed mineralogical departments at St. Petersburg University, that trained A.N. Karnozhitskij[1297] and Sergei Fedorov Glinka.[1298] A huge impact was made in 1888 by the discovery of M.T. Erofeev and P.A. Lachinovym of diamond grains with in a recently recovered meteorite. The views of Erofeev on the structure influenced a Russian scientist who had emigrated to Armenia, D.E. Artsruni.[1299] He did extensive studies on the mineralogy of the Urals and in chemical crystallography.

Totally separate from other mineralogists and crystallographers of the period is the figure of the professor of physics at the Artillery School of Aksel' Vil'gel'movich Gadolin.[1300] In his famous *The Conclusion All Crystallographic Systems and their Subdivisions of one overall Beginning* (1867) presented the most important generalization of crystallography to its time. His derivation of the 32 crystal symmetry classes played an enormous role in crystal studies and mineralogy to the present day, being basis for the crystallographic classification of minerals.

At the same time the first microscopic examinations of minerals in the rocks was introduced to Russian science. The pioneers of microscopy in Russia are the renowned father of Russian geology Alexander Petrovich Karpinski,[1301] who was a professor at the St. Petersburg University.

### Fedorov

A new period not only in the study of crystallography, but also in the studies of mineralogy and petrography is connected with the appointment to the Mining Institute of the brilliant Evgraf Stepanovich Fedorov.[1302] The

[1296] Mikhail Vasil'evich Erofeev [1839-1899] graduated from St. Petersburg University in 1863. In 1879 he was appointed professor of crystallography and mineralogy at the University of Warsaw, but in 1880 he returned to St. Petersburg with a professorship at the Forest Institute. He published papers on the structure of crystals, and helped determine the presence of microscopic diamonds in some meteorites.

[1297] A.N. Karnozhitskij [1867-1907] ...

[ ]
[ Biography Needed ]
[ ]

[1298] Sergei Fedorov Glinka [1855-1924] was a professor of mineralogy and crystallography at the University of St. Petersburg.

[1299] D.E. Artsruni [1847-1898] ...

[ ]
[ Biography Needed ]
[ ]

[1300] Aksel' Vil'gel'movich Gadolin [1828-1892] graduated the Mikhail Artillery School in 1849 and remained their to teach. He developed techniques for building high velocity canons, which significantly increased the range a shell could be propelled. He is remembered in crystallography for deriving the 32 macrosymmetrical crystal groups, and devising a method for depicting these groups on a sphere that is still in use to the present. The St. Petersburg Academy of Sciences awarded him the Lomonosov prize for his crystallographic work, 1868.

[1301] Alexander Petrovich Karpinski [1847-1936] graduated from the Mining Institute of St. Petersburg in 1866. He then became a professor of geology at the Institute, teaching there until 1896. He then took on a series of roles with in scientific committees of the government, but always trying to use natural resources for the benefit of the Russian people. He was also for many years the president of the Russian Academy of Sciences.

[1302] Evgraf Stepanovich Fedorov [1853-1919] studied mathematics indepentently while attending the St. Petersburg Military Engineering School, the Military Medical and Surgical Academy, and the Technological Institute. Upon graduating from the Mining Institute in 1883, Fedorov took an appointment with the Mining Department where he was included in an expedition to explore the northern Urals. He extended a very strong influence on the developement of mineralogy and crystallography at the end of the nineteenth century. His

beginning of his works coincide with the later decades of the 19th century. At that time in imperial Russia there is much opportunity. The 1890's are noted by a significant lift in industrial activity. Technology rapidly is developed and improved, and in many fields of the exact sciences great successes are achieved. The construction of new industrial plants, the developing railroad system cause a sharp increase in the need for different ores, fuel, and oils. The increasing requirements for this industry from the aspect of mining make it necessary, besides description, to be turned to the explanation of the reasons for phenomena, in an effort to increase the effectiveness of scientific works. Thus began a new period in Russian mineral science that can be described as analytical, with the precise analysis of the facts of mineralogy.

This period provides a period for the synthesis of all the accumulated data that had come before, which served as material for deep theoretical constructions. From this stage it is first of all necessary to name the brilliant development of the Fedorov theory of the structure of crystalline substance. Beginning even with his first scientific works, Fedorov approaches the problem of the structure of crystals. His numerous transactions in this region are crowned by the brilliant theoretical deduction of 230 three-dimensional symmetry groups, or the 230 possible arrangements of atoms with in a three dimensional crystal structure, which received experimental confirmation bye the use of X-ray crystallographic studies.

The second emphasis of Federov during his tenure at the school of the Mining Institute was in the determination of the chemical composition of minerals in connection to their crystal structure. This so-called "crystallochemical analysis" would eventually be used in institutions of higher learning through out the scientific world. Federov approached the determination of the composition of minerals from the angular values of their faces through the preliminary determination of the type of the structure of minerals. With a clique consisting of his small group of students and colleagues Fedorov undertook the complete revision of the general forms of minerals and crystals from a crystallographic-chemical point of view. His achievements in this direction found their complete expression in the capital labor in his *Reign of Crystals*, published after his death in 1920.

The third most important direction of the work of Fedorov, which also became the special feature of the school of Mining Institute, consists in his development of the methods of optical studies of minerals. For these studies, Fedorov invented the theodolite or universal optical stage that easily allowed easily for the precise, and it is possible to say, elegant determine in the crystals of minerals the position of the optical indicatrix. This innovation became a tool of every mineralogist and petrographer through out the entire world for decades.

Some scientific work Fedorov carried out was in conjunction with V.V. Nikitinym.[1303] The latter taught mineralogy in the Mining Institute from 1901 to 1922, after replacing at this post of G.G. Lebedev.[1304] Lebedev had taught in the Institute from 1875 through 1905, and he authored a popular *XXXXXX* [Textbook of Mineralogy], that was published twice in 1903 and in 1907, and is still highly regarded as containing useful information. Nikitin further developed the theodolite method and composed the extensive monograph *XXXXXXXX* [Universal Method of Fedorov] (1915). In the teaching of descriptive mineralogy he adhered to a strict system, according to which he built his own *XXXXXXXX* [The Summary of Mineralogy] (1911-1915), which contains numerous and detailed information on the morphology of

clssification of symmetry groups of crystallized matter lead directly to the working out of a new nomenclature of systems and point group symmetries known as Fedorov-Groth nomenclature. Fedorov's goniometer modifications produced a revolution in the method of investigating minerals. Invented the universal stage (Fedorov table) for petrographic microscopes that would locate the specimen at the center of two glass hemispheres (Fedorov method).

[1303] V.V. Nikitinym [1867-1942] ...
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[ Biography Needed ]
[ ]

[1304] G.G. Lebedev [1849-1909] ...
[ ]
[ Biography Needed ]
[ ]

minerals.

Developing at the same time and in another direction was the mineralogy at the St. Petersburg University. After the death of the young professor of mineralogy Platon Aleksyeevich Puzuirevski[1305] and withdrawal from the University of Mikhail Vasil'evich Erofeeva[1306] the mineralogical department was headed by Vasilii Vasilevich Dokuchaev,[1307] the famous founder of the Russian pedology. In his lectures on the mineralogy Dokuchaev especially emphasized the dynamic side of the science, which in terms of the time was sharply different from other mineralogy courses that treated mainly questions of descriptive mineralogy. Dokuchaev had enormous influence on his students and created new university school in the mineralogy and the pedology.

Among his students were the mineralogists Petr Andreevich Zemjatchenskij,[1308] who working along the line developed by Dokuchaeva made significant contributions to the mineralogy of sedimentary rocks. He is considered a founder in the studies of sedimentary mineral species and in the disciplines of soil science. Employed as an instructor at the University from 1898 to 1940, Zemjatchenskij was the mentor to several important mineralogists including V.I. Iskiul.[1309]

### 11.2.6.50.3 Russia (20th Century to 1917)

At the conclusion of the 19th century, almost all mineralogy departments of Russian universities and technical and medical schools were occupied not with mineralogists, but by geologists. At Moscow University the department has been occupied by M.A. Tolstopjatov,[1310] who was a paleontologist and G.E. Shurovskogo,[1311] who was a geologist. It is possible to say that there were no mineralogists in the department of mineralogy at Moscow University at that time. However, the bloom of mineralogy at Moscow University began in 1891, with the joining to this department of Vladímir Ivanovich Vernadsky.[1312] He radically converted and renewed the training and scientific work of the department, which had for a long time been in a steep decline. A.E. Fersman said: "The time from 1890 through 1911, i.e., the almost 25 years of scientific work, was connected with the life V.I. Vernadsky and his work at Moscow University. Specifically, here and there in the modest apartment in the university court, and then in the quiet alley of Arbat were born his most sparkling scientific

[1305] Platon Aleksyeevich Puzuirevski [1831-1871] was an instructor of mineralogy at the University of St. Petersburg.

[1306] Mikhail Vasil'evich Erofeeva.

[ ]
[ Biography Needed ]
[ ]

[1307] Vasilii Vasilevich Dokuchaev [1846-1903] Dokuchaev taught at the St. Petersburg University and worked at various and numerous scientific and governmental groups. He made important studies of the formation of river valleys, the genesis of landforms, and geomorphology. He considered soil as a special material that had been created from climate, bedrock, plant and animal life, age of the land, and topography. His studies of soils caused him to formulate ideas about the complex connections soil forming factors, and led him to create a classification of soils.

[1308] Petr Andreevich Zemjatchenskij [1857-1942] graduated from the University of St. Petersburg in 1882. He became the keeper of the mineralogical museum. In 1898 he was appointed professor of mineralogy in the Universities geological department. He participated in several expeditions in Russia, studying soils, geology and hydrogeology. He was elected a member of the Russian Academy of Sciences in 1928.

[1309] V.I. Iskiul [1881-1932] ...

[ ]
[ Biography Needed ]
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[1310] M.A. Tolstopjatov [1836-1890] ...

[ ]
[ Biography Needed ]
[ ]

[1311] G.E. Shurovskogo [????-????] ...

[ ]
[ Biography Needed ]
[ ]

[1312] Vladímir Ivanovich Vernadsky [1863-1945] graduated from St. Petersburg University in 1886, becoming an assistant in Moscow University. In 1888, he had post graduate studies under Groth in Münich, and in 1889-90 in Paris he worked in the laboratories of Fouqué, Le Chatelier and Curie. In 1891, he returned to Moscow becoming a private docent. From 1898 to 1911, he was professor of mineralogy. He was also post-rector from 1906-11. When he was elected to the Academy of Science in St. Petersburg in 1906, he also was given charge of the mineral collection. On the relocation of the Academy to Moscow, he became director of the biogeochemical laboratory. His research was principally in geochemistry and the formation of minerals.

ideas ... In Moscow he created around himself an excellent scientific school, by accumulating young university people. This school became the powerful source of new ideas and new undertakings."

An exceptional scientist, Vernadsky reformed Russian mineralogy, and became a founder of modern geochemistry, biogeochemistry, and radio-geology. His understanding of geological science was caused by deep historical reasons. The economic lift of industry in Russia of the 1890's noted above gave a powerful push to the study of ore deposits, and in the geological and mineralogical cycle of their formation. Since the correct interpretation and methodology for prospecting revolves around the knowledge of the mineral vein genesis, mineral studies turned to studies of their origin, which led to new basis for the classification of ore deposits that were based on the conditions and processes during the formation of the ores. Vernadsky emphasized the mineralogical processes of the earth's crust focusing special attention to the dynamic interaction of mineral formation, and not simply a study of their static products. He treated mineralogy as a history of the minerals of the earth's crust.

Using results from his laboratory experiments, Vernadsky develops his hypothesis for the formation of alumosilicates, by considering the conditions that formed different compounds between the salts of different alumo-flint acids. He presented his views in a series of original articles, and especially in *XXXXXXX* [The Mineralogy] (1899-1910) and in *XXXXX* [The Histories of the Minerals the Earth's Crust] (1923-1936), which may be characterized as extraordinary publications in the scientific literature of the world.

The ideas of Vernadsky began to impact other European scientists, especially in Poland, the Czech Republic, and France. Other prominent Russian mineralogists attended Vernadsky's courses at Moscow University. The most brilliant student was Aleksandr Evgenievich Fersman, who was assistant to Vernadsky at the University. Since the Fersman is connected mainly with the Academy of Sciences of the USSR, his activities will be mentioned below. Another disciple, Yakov Vladimirovich Samoilov[1313] gave special attention to the mineralogy of agricultural soils and to determining the bio-geochemical processes that led to the formation of minerals in the sedimentary rocks. In 1911, because of government interference, Vernadsky suddenly left Moscow University and together with a large group of scientific colleagues, relocated to St. Petersburg. There he began a new period of activity that also left an important mark on Russian mineralogy.

In St. Petersburg, and later Petrograd Vernadsky, it can be said, created anew the mineralogical work in the Academy of Sciences. Although the Academy had existed for sometime (founded 1724 ?????), it was principally an honorary position to be appointed to its ranks. There were neither mineralogical laboratories nor institute associated with the Academy, and the academicians prior to Vernadsky like Koksharov and Eremeev had actually worked in the Mining Institute and only published their papers in the Academy of Science's *Transactions*. After leaving Moscow University and after becoming in 1912 an ordinary academician, Vernadsky focused his attention, first of all, on the development of mineralogical work in the Academy's geological museum, for which he actively solicits for the organization of its laboratories and the installation of equipment for chemical-mineralogical studies.

Victor Ivanovich Vorobyev[1314] was a gifted mineralogist and the keeper of the mineralogical collections of museum when he was tragically was killed during field work in the Caucasus.

[1313] Yakov Vladimirovich Samoilov [1870-1924] was an eminent mineralogist, crystallographer and economic geologist. He graduated from Novorossisk University in Odessa in 1893, becoming a professor at Moscow University from 1907 to 1925. He studied barites, celestites, iron ores and phosphates deposits.

[1314] Victor Ivanovich Vorobyev [died 1906] graduated from St. Petersburg University, and became in 1900 manager of the museum of the departments of mineralogy and geology. He was especially interested in the mineralogy of the Urals and the Caucasus, where he made special studies of the formation and crystallization of tourmaline in the pegmatites of those mountain systems. He died at a young age after falling into the crevasse of a glacier while working in the Caucasus.

V.I. Kryzhanovskij[1315] replaced Vernadsky as curator of the mineralogical museum.

In the academy Vernadsky together with his colleague Constantine Avtonomovich Nenadkevichem,[1316] an excellent thin analyst, he directs mineralogy to the study of rare minerals and the rare component parts of common minerals. Using a large spectroscope, Vernadsky investigates in the minerals the content of scandium, cesium, rubidium, and thallium. This work marked the modern beginning of the science of geochemistry.

During his tenure at the Academy of Sciences, Vernadsky marked a new direction in mineralogy. In connection with the first World War, the Academy created a commission for the study of the natural resources of Russia (KEPS). The development of the mineral resources of the country and the direct maintenance of the current military needs with respect to needs to these or other minerals and ores for the defense industry was the task of commission. Scientific questions in connection with the commission were tightly interwoven with purely practical questions. In particular, the role of technology as it relates to raw mineral material is outlined. However, these developments in Russian mineralogy would only be fully realized after the revolution in the work of the Academy in applied mineralogy.

In other mineralogical cells of Russia, not numerous in the pre-revolutionary years, mineralogical studies on those existed then to possibilities they conducted only in the extremely limited volume.

The crystallographer Georg (Yuri Viktorovich) Wulff[1317] worked intimately with Vernadsky. He was among the first in the world to perform studies on the internal structure of minerals through the use of X-ray analysis.

In St. Petersburg, an interesting center of mineralogical work with a special direction was created by the outstanding petrographer Franz Yulevich Levinson-Lessing.[1318] After graduating from St. Petersburg University in 1883, where he had been a student in mineralogy of V.V. Dokuchaeva, Levinson-Lessing furthered his education by working with Vernadsky, and in 1892 he was appointed to the department of mineralogy and petrography at the University of Derpskom (now Tartu) University. In 1902, he relocated to the St. Petersburg Polytechnic Institute, where using the laboratories of the physical chemistry departments, he develops important studies in the physical chemistry of minerals and rocks.

### Fersman

Another influential person in St. Petersburg was Aleksandr Evgenievich Fersman [1883-1945][1319] who had studied at the

[1315] V.I. Kryzhanovskij [1881-1947] ...

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[ Biography Needed ]
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[1316] Constantine Avtonomovich Nenadkevichem [1880-????] was a student of Vernadsky, graduating from Moscow University in 1902. He went on to work at a number of geological positions, including the geological and mineralogical museum, Geological Institute and the Institute of Mineralogy. His publications deal with practical questions of new methods for detecting new mineral deposits and the extraction of rare metals from their ores. In 1926 he developed a method to determine the age of pitchblende through chemical operations.

[1317] Georg (Yuri Viktorovich) Wulff [1863-1925] had a distinguished career teaching in Poland and Russia, where he was a professor at Moscow University from 1918. Inspired by research published by Pierre Cure, he formulated in 1916, the Curie-Wulff principle regarding the theoretical surface energies during crystal formation. In 1909 he also invented the Wulff net method of stereographic projection of a sphere. This led to his demonstration of deviations between real crystals and theoretical ideals.

[1318] Franz Yulevich Levinson-Lessing [1861-1939] graduated from St. Petersburg University in 1883. After graduation, he taught at the University of Yurev from 1893 to 1902, followed by the Polytechnic Institute from 1902 to 1930. He was a pioneer in petrology, and helped to create it as an independent field of study. He proposed in 1898 a classification of rocks based upon their chemical makeup.

[1319] Aleksandr Evgenievich Fersman [1883-1945] studied under Vernadski. In 1907, he graduated from Moscow University, and immediately continued his studies with Lacroix in Paris and the Norwegian geochemist Victor Moritz Goldschmidt [1888-1947] in Heidelberg. In 1909, he began teaching at Moscow University, and in 1910 he became a professor at the People's University, where in 1912 he introduced a course in geochemistry. Also in 1912, Fersman was appointed professor of mineralogy in St. Petersburg and senior curator of the Mineralogical Museum of the Academy of Sciences. Fersman was an investigator of incredible industry, and his studies include the mineral resources of the Urals, Crimea, Caucasus,

Mining Academy in Novorossiyak and at Moscow University, where he became a student of Vernadsky, whose influence Fersman carries on in his own researches. In 1907, he traveled abroad and studied under Alfred Lacroix, Henri Rosenbusch and Victor Goldschmidt. After returning to Russia, Fersman was appointed in 1915 to be professor of mineralogy and crystallography at the University of St. Petersburg. In this role he insisted on the importance of developing Russia's natural resources. He led numerous expeditions to the Urals, Crimea, Kola Peninsula, etc., which caused the discovery of large deposits of sulfur, rare earths, and other minerals. Fersman was especially interested in pegmatites and the paragensis of the rare minerals that occurred in them. His experiments showed the successive stages of their formation as conditions in the pegmatite changed. This voluminous work on pegmatites led him to study the behavior of chemical elements and minerals in the earth's crust and was thus able in some cases to predict where minerals of economic value would be found. His *XXXXXXX* [Geochemistry of Russia] (1922), *XXXXXXX* [The Search for Mineral Deposits on the Basis of Geochemistry and Mineralogy] (1939) are classic works in economic geology. During his lifetime, Fersman also wrote many popular-style books on minerals and gemstones.

Numerous experiments on the synthesis of minerals were performed by K.D. Khrushchev[1320] in the Military Medical Academy. Work on the mineralogy of the Ukraine was conducted at the University of Kiev. There under the management of the professors K.M. Feofilaktova,[1321] P.Y. Armashevskiy,[1322] and V.E. Tarasenko,[1323] there are taught a number of future mineralogists. In 1908 at new Mining Institute located at Dnepropetrovsk the former Vernadsky student L.L. Ivanov[1324] was appointed instructor of mineralogy.

In Kazan mineralogical studies were produced by P.I. Mole.[1325] In Siberia the minerals were investigated by M.A. Usov,[1326] P.L. Dravert,[1327] and Pavel Prokopepich Pilipenko,[1328] that paid special attention to the mineralogy of the Altai. He also developed work on the mineralogy of the Crimea, Caucasus and other regions.

This survey now approaches 1917, the year of the October Socialist Revolution which overthrew the Tsar and imperial government. It is a critical point in Russian political and scientific structure which would led to a new period in the development of mineralogy in Russia.

Topographical Studies

1935 G. Gorbunov and D.I. Shcherbakov., *Non-metallic Minerals, U.S.S.R.* Moscow, Acad. Sci., 1935-1942. 2

Kazakhstan, Tukestan, the Altai, Transbikalia, northern Mongolia, Karelia and the Kola Peninsula. From this work several discoveries of major economic mineral deposits were made.

[1320] K.D. Khrushchev [1852-1915] ...
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[ Biography Needed ]
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[1321] K.M. Feofilaktova [1818-1901] ...
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[ Biography Needed ]
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[1322] P.Y. Armashevskiy [1851-1919] ...
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[ Biography Needed ]
[ ]

[1323] V.E. Tarasenko [1859-1926] ...
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[ Biography Needed ]
[ ]

[1324] L.L. Ivanov [1877-1946] ...
[ ]
[ Biography Needed ]
[ ]

[1325] P.I. Mole [1852-1914] ...
[ ]
[ Biography Needed ]
[ ]

[1326] M.A. Usov [1889-1939] ...
[ ]
[ Biography Needed ]
[ ]

[1327] P.L. Dravert [1879-1945] ...
[ ]
[ Biography Needed ]
[ ]

[1328] Pavel Prokopepich Pilipenko [1877-1940] was a 1902 graduate of Moscow University where he was a student of Verndsky. He then became an assistant professor, before being appointed professor of mineralogy to Moscow University (1926-1930), and the Geological Survey of the USSR (1930-1940). His publications with the formation of minerals and the regional mineralogy of the Altai Mountains.

vols. 591 p.; 447 p. [In Russian.].

1940 A.E. Fersman and N.A. Smolianinov., *Minerals of the U.S.S.R.*, Vol. 1 (1940), *Native Elements*. 328 p., illus. Vol. 2 (1940) *Sulphides, Sulphosalts and Similar Compounds*. 747 p., illus.

Black Sea

1927 P.N. Chirvinsky., [Useful minerals of Kuban and the Black Sea]. Rostov on Don, 1927. 232 p. [in Russian].

Crimea

1938 S.P. Popov., *Mineralogy of Crimea*. Moscow and Leningrad, 1938. 352 p. [in Russian].

Kola Peninsula

1926 A.E. Fersman., "Minerals of the Kola Peninsula," *American Mineralogist*, **11** (1926), p. 289-299.

1937 A.E. Fersman and E.M. Bohnstedt., *Minerals of the Khibina and Lovozero Tundras*. Lomonosov Inst. Acad. Sci. U.S.S.R., 1937. 152 p.

Urals

1837 Gustav Rose., *Mineralogisch-geognotische Reise nach dem Ural, dem Altai und den Kaspischen Meere*. Berlin, 1837-1842. 2 vols.

1845 N.I. Koksharov., "Alphabetical list of minerals found in the Ural Mountains or on their flanks," in: *The Geology of Russia*. London and Paris, 1845, vol. 1, appendix E.

1941 A.E. Fersman and A.G. Betekhtin., *Mineralogiya Urala*, Part 2. Moscow, Akad. Nauk SSSR, 1941. 414 p., illus.

### 11.2.6.91 Slovakia (Slovenská)[1329]

Topographical Studies

1939 F. Stavik., *Minerals of Slovakia*. Praha, 1939. 62 p., maps (in Czech).

1984 Ivan Herčko., *Minerály Slovenska*. Banskâ Stiavnika, Vydavatelstvo Osueta, 1984. 235 p. [Bibliography, p. 200-211.].

1990 M. Kodera., *Topograficka Mineralogia Slovenska*. Bratislava, VEDA, 1990. 3 vols., 1593 p., illus. [Regional mineralogy of Slovakia.].

### 11.2.6.99 Yugoslavia

The histories of mineralogy in the various regions of the former Yugoslavia are given under the names of the independent nations that now exist. For descriptions see Bosnia and Herzegovina, Croatia, Macedonia, Serbia, and Slovenia.

Topographical Studies

1951 Vasilije Simic., *Istoriski razvoj našeg rudarstva*. Beograd, Izdavacko-Štamparsko preduzece Saveta za energetiku i ekstraktivnu industriju, 1951. 438 p. illus., maps. [Mines and mineral resources of Yugoslavia.].

### 11.2.6.99.1 Bosnia and Herzegovina[1330]

Mineralogy and petrology developed in Bosnia and Herzegovina through the search for useful minerals and rocks in the country. After 1830 the main development in mineralogy came from investigating the mining districts of Tuzle, Ljubije, and Vareša located in the region. The first topographical mineral studies of the area were made during this time and include investigations by A. Conrad, R. Helmbacher, and R. Baron. The mineralogists F. Hauer, K. Vrba, and F. Foulon also studied mineral species that came from the country, while V. Radinky and M. Kašpatić extended knowledge of the petrology.

After 1899, most significant mineralogical work in Bosnia and Herzegovina developed through a systematic exploration of the country for raw mineral materials. The Istria mercury deposits were also studied by F. Katzer, who

[1329] Further historical information may be found in: R. Ďud'a and J. Galvánek., "História typových minerálov zo Slovenska," *Bulletin mineralogicko-petrografického oddělení Národního muzea v Praze*, **7** (1999), p. 260-266. [History of topographical mineralogy in Slovakia?]. • Pavlo Grecula., *História geológie na Slovensku do roku 1918n*. Bratislava, 2002. 292 p. • Ivan Herčko., "Seltene Minerale aus der Skowakischen Sozialistischen Republik und ihre Entdecker," *Geologie*, **20** (1971), Heft 4/5, p. 500-503. [Rare minerals of Slovakia and their discoverers.] • *ibid.*, "Z činnosti členov Mineralogickej Spoločnosti v Jene pošobiacich na strednom Slovensku," *Dějiny Věd Tech.*, **13** (1980), p. 1-17. [On the activities of the members of the Mineralogical Society of Jena in central Slovakia.] • *ibid.*, ed., *Z dejín geologických vied na Slovensku*. Martin, Vydavatelstvo Osveta, 1981. 285 p. [History of geology in Czechoslovakia, and peripherally Poland and Hungary.] • *ibid.* and J. Jancsy., "Development of geological mapping in Slovakia" (pp. 129-37), in: E. Dudich, ed., *Contributions to the History of Geological Mapping*. Proceedings of the Xth INHIGEO Symposium 16-22 August 1982, Budapest, Hungary. Budapest, 1984. • Petr Rybár, et al., *História baníckeho vysokého Školstva na Slovensku*. Košice, 2001. • Josef F. Svoboda., *Naucný Geologický Slovník*. Praha, Nakl. Ceskoslovenske akademie ved, 1960-61. 2 vols. [Encyclopedia of Czech geology including biographies of geologists.] • Otto Tomecek and Ivan Herčko., *Chémia a mineralógia na Banícke akadémii v Banskej Štiavnici*. Banská Bystrica, Slovenská Chemická Spoločnost, 2001. [1]-123, [3] p., illus. [A richly illustrated history of chemistry and mineralogy at the Schemitz Mining Academy.]

[1330] Further historical information may be found in: *Enciklopedija Jugoslavije*, **6** (1965), p. 126-128. • Friedrich Katzer., *Geschichtlicher überblick der geologischen erforschung Bosniens und der Hercegovina*. Zum 25. Sarajevo, Seibstverlag; Buchdruckerei der Bosnischen Post, 1904. 46 p., portraits. [Historical review of the geological research in Bosnia and Herzegovina.] • Fabijan Trubelja and Ljudevit Barić., *Minerali Bosne i Hercegovine*. Knjiga I — Silikati. Knjiga II — Nesilikati. Sarajevo, 1979-84. 2 vols. 452 p, illus., index, biblio.; 571 p., illus., index, biblio. [The first section of volume one contains a good history of mineralogical research in Bosnie and Hercegovia.] • *ibid.*, "Mineralogy and crystallography in Bosnia and Herzegovina in the last 150 years," **Godišnjak jug. Centra za Kristalografiju**, **20** (1985), p. 53-73

identified many mercury containing minerals from the locality.

Topographical Studies

1979 Fabijan Trubelja and Ljudevit Barić., *Minerali Bosne i Hercegovine*. Knjiga I — Silikati. Knjiga II — Nesilikati. Sarajevo, 1979-84. 2 vols. 452 p, illus., index, biblio.; 571 p., illus., index, biblio. [The first section of volume one contains a good history of mineralogical research in Bosnie and Hercegovia.].

### 11.2.6.99.1 Croatia (Hrvatska)[1331]

The nation of Croatia located in southeast Europe was from 1919 to 1992 part of the former Yugoslavia. Prior to that time it was a region within the Austro-Hungarian Empire, and ruled by the Hapsburgs.

The beginning of modern research into the minerals and geology of Croatia are linked to the founding of the Zagreb Narodnog Muzeja (Zagreb National Museum) in the first half of the nineteenth century. Mineralogy and petrology of the Moslavina Mountains was studied by the amateur geologist Ljudevit Vukotinović in 1852 and in 1868. Later, he reported on the petrographic structure of the Kalnik and Zagreb mountain ranges. Duro Pilar from 1870 was head of the mineralogical and geological departments of the National Museum. He reported in detail on the minerals, rocks, and geology of the Zagreb mountains, while his other research described the Kupa River basin and the Moslavina Mountains extending into some areas of Bosnia.

Mineralogy and petrology were further developed as scientific disciplines in the country by Mijo Kišpatić, curator of the mineralogical collections at the Zagreb Museum as well as a professor at the city's university. Using optical instruments such as a polarizing microscope, he studied the structure of minerals and rocks, especially the changes effected by the metamorphic process. His field work included the petrology of the Moslavin Mountains and studying of the igneous and metamorphic rocks of the country. He investigated especially the serpentine deposits of Bosnia, correctly theorizing that they had formed as the result of metamorphic alteration rather than direct extrusion from within the earth. Kišatić also promoted investigations on the mineral structure of bauxite, and other ores of aluminum. His most important role in mineralogy for Croatia was his position as curator of the mineralogical collection at Zagreb. He initiated a campaign of specimen acquisition from localities throughout Europe, but always concentrated on specimens that originated from the regions of Croatia, Bosnia, and the neighboring areas. They remain the core of the present mineralogical-petrographical collections at the museum.

After Kišpatić, the professorship of mineralogy and petrology and the curatorship of the collection passed to Fran Tućan. His major research was into the caves, and deposits of aluminum and iron in the region. He attempted to fully describe the complex geology and petrology of different parts of Yugoslavia by mapping the eruptive and metamorphic formations of the region. Tućan also did mineralogical research on mimetite, kemerite, aragonite, oynx, and jade.

Other scientists continued to study the petrology of the country, introducing new methods to the work. These include L. Marič, who investigated the andesite-dacite complexes of the region. He showed relationships between the geology and geochemistry of Bulgaria, Romania, and the other countries of the former Yugoslavia. He compiled the first mineral paragenesis of the region, and studied in particular minerals from the area that contained antimony and tungsten.

M. Tajder studied clinoclore, the amphibole silicates, and nemalite. He theorized how minerals crystallized from magma, and especially studied the effect of sodium in the crystallization process.

Crystal morphology and crystal optics were how Lj. Buriča investigated his minerals

[1331] Further historical information may be found in: *Enciklopedija Jugoslavije*, **6** (1965), p. 126-128. • Alexander C. Niven., "Geology in Croatia," *Geological Magazine*, **81** (1944), no. 3, p. 118-120. [Reviews the development of knowledge of the geology of Croatia, giving the names and their contributions.] • Jugoslavenska akademija znanosti i umjetnosti, Zagreb., *U proslavu petdesetgodišnjice prieporoda hrvatske knjige god. 1885.* U Zagrebu, U akademickoj knjišari L. Hartmana, 1885. [4], 313 p. [This history and criticism of Croatian literature contains in one section a history of the progress of mineralogy and geology in the Croatia, Slavonia and Dalmatia from 1835 to 1885 ("Napredak mineralogije i geologije u Hrvatskoj, Slavoniji i Dalmaciji od god. 1835 do god. 1885.")]

and crystals. Using a two-circle goniometer and a Federov theodolite, he developed studies of plumozite, realgar, desclozite, wulfenite, barite, fluorite, ludlamite, and vivianite.

### 11.2.6.99.1 Macedonia[1332]

Mineralogical research in the territory of Macedonia began in a modern sense at the end of the nineteenth century. Study of the mineralogy of antimony-arsenic deposits at Alšaru in the Kožufu Mountains led to the discovery of the new mineral species lorandite ($TlAsS_2$) and vrbaite ($Tl_4Hg_3Sb_2As_8S_{20}$). Other minerals studied from this locality include realgar, stibnite, antimony, auripigmenitite(?), valentinite, senarmontite, arsenolite, and other species of the paragenesis. They were investigated by B. Jezek, Fr. Krehlik, J. Krenner, and Victor Goldschmidt. Prior to World War I, N. Erdmannsdörff studied the minerals of the region, discovering a new variety of mica containing excess chlorine, which he named after K. Kossmat, who worked on the geology of Macedonia. Erdmannsdörff described corundum and diasphor of the region. S. Bončev also preformed mineralogical and petrographical studies of the country.

After World War I, F. Tućan continued mineral investigations of Macedonia. His most important studies were descriptions of the Alšara locality where he found halojzite(?), in the area of the mountains of Kitke and Jakupice he found žadeite(?). Lj. Barića and S. Pavlovića also studied the mineralogy of eastern Macedonia.

### 11.2.6.99.1 Serbia (Srbija)[1333]

Forming part of the former conglomerated nation of Yugoslavia from 1919, Serbia became independent in 1992. Prior to World War I it was included with in the vast territory of the Austrian-Hungarian Empire ruled by the Hapsburgs.

Scientific mineralogy in Serbia can be tied to Josif Pančić [1814-1888] who as an instructor at Belgrade's University taught mineralogy and geology from 1853 to 1880. During this time a mineralogical cabinet was established for the purpose of basic teaching. By the end of the nineteenth century it contained more than 1700 crystallized specimens, 1000 ore and rock samples, 200 crystal models, a polarizing microscope, and a goniometer. Pančić published a textbook, *Mineralogija i Geologija* in 1867 that he used as a manual in his classes.[1334] It includes information on about 60 mineral species and 20 different rock types found in the borders of the Serbian territory.

In 1880 lessons on mineralogy and geology at the University were taken over by Jovan Žujović [1856-1936]. In 1900 the first significant description of Serbia's geology appeared.[1335] The closely related study of petrology was developed by Sava Urošević, who also taught at the University. In 1889 when mineralogy and petrology were separated from geology, becoming its own department, Urošević became an instructor in mineralogy and petrology in the new department. His field work was on the various types of rocks found in the Serbian territory. Sime Lozanića did research on the minerals avalite from Šupije and alexsandrolite from Rudnjaka. However, he primarily studied intrusive granites in Serbia, and the minerals that formed them. In 1903, he published his textbook on geometrical crystallography, *Geometriska Kristalografia*, followed in 1910 by his text on physical crystallography, *Fizička Kristalografia*, and finally his most complete general volume of mineralogy, *Mineralogija* in 1928. At the start of the twentieth century, mineralogy and especially crystallography were the areas that Svetolik Stevanović directed his research. He distinguished himself in his study of cinnabar from Avalskim.

Between 1919 and 1941, Serbian mineral-

[1332] Further historical information may be found in: *Enciklopedija Jugoslavije*, **6** (1965), p. 126-128.

[1333] Further historical information may be found in: *Enciklopedija Jugoslavije*, **6** (1965), p. 126-128. • Vidojko Jović., *Iz istorije geologije u Srbiji*. Belgrade, Jantar grupa, 2003. 264 p. [On the history of geology in Serbia.; ISBN 86-84167-02-3.]

[1334] Josif Pančić., *Jestastvenica - Mineralogija i geologija*. Beograd, 1867. [Reprinted, Beograd, 1998. 339 p. [ISBN 86-17-05894-3.]

[1335] *Geologije Serbia*, 1900.

ogy is carried forward by a small group of researchers, mainly employed in the department of mineralogy and petrology of Belgrade University. In 1930 a geological institute was established in Belgrade, which was the first institute of its type established in Serbia. Branimir Dimitrijević prepared a petrographic-mineralogical study of the Anals, and Jovan Tomić conducted similar research about the Kotleniku. Much other research was carried on systematically looking for large ore deposits in the territory of Serbia. However, the extensive mineralogical testing in Serbia discovered few new mineral species, but recovered takovite.

Topographical Studies

1910 D.J. Antula., *Les Richesses Minérales de la Serbie*. Marseille, 1910. 32 p.

### 11.2.6.99.1 Slovenia (Slovenija)[1336]

An early mineralogical description of the geology of Slovenia occurs in *Die Ehre des Herzogthums Krain* (1689). The first scientific investitgators were J.V. Valvasor, Ž. Zois, and F.J.H. Hohewarth, who deal especially with describing the minerals and rocks they collected in the country. The collection of Žige Zois [1747-1819] developed into one of the most complete that existed in Europe of the the time, containing more than 4,000 pieces form localities across Europe. Zois was a competent mineralogist who contributed greatly to the science. In his honor the mineral species zoisite is named.[1337] In 1828 ownership of the collection passed to the Natural History Museum in Ljubljana.

From 1755 to 1784 the Austrian mineralogist and botanist Franz Xaiver Wulfen worked in Ljubljana, studying the plants and minerals of the Carinthia mountains. he was the first in a line of Austrian mineralogists and geologists to study the area. After the founding of the Geological Society of Austria in 1843 and the Geological Suvey of Austria in 1848, a project of systematic geological mapping of the Slovenian province was commenensed. The mineralogical-petrographical problems encountered during the survey were studied by: F. Rolle, T. Zollikofer, D. Waterdog, R. Drasche, E. Hatle, J.A. Ippen, F. Eigel, C. Doelter, F. Kossmat, F. Teller, H. Vetters, H. Graber, F. Kruetz, E. Reyer, and F. Benesch.

In 1919 at the newly established University of Ljubljana a Mineralogical Institute was established. It was organized by Karel Hinter Lechner [1874-1932], who was professor of mineralogy and petrography. Vasilij V. Nikitin [1867-1942] lectured on minerlaogy and petrolography at the University. He also authored the first Slovenian textbook in mineralogy and crystallography, petrology, and ore deposits,[1338] and worked to improve the optical methods of Federov.

Several mineralogical textbooks in the Slovene language were published. In 1867, a translation of S. Fellöcker by Fran Erjavec appeared,[1339] It was a textbook used to teach mineralogy in the secondary schools. In 1883 Erjavec wrote an independent text.[1340] In 1871 Janez Zajec translated Schroder's natural history, including

[1336] Further historical information may be found in: *Enciklopedija Jugoslavije*, **6** (1965), p. 126-128. • Peter Bancroft., "Slovenia Natural History Museum, Ljubljana, Yugoslavia," (pp. 42-43) in: *Mineral Museums of Eastern Europe*. Published as *Mineralogical Record*, **19** (1988), No. 1, 52 p., illus. • Ramovš, Anton., "Über die geologischen Untersuchungen im slowenischen Gebiet undter der Leitung der Geologischen Reichsanstalt in Wien von 1849 bis 1918," (pp. 69-94) in: *Geologie ohne Grenzen. Festschift 150 Jahre Geologische Bundesanstalt*. [Publised as *Abhandlungen der Geologischen Bundesanstalt*, **56/1** (1999).] • Joze Rus., "Triglav v herojski dobi geologske vede (Der Triglav im heroischen Zeitalter der geologischen Wissenschaft)," *Geografski Vestnik (Bulletin de la Société de Géographie de Ljubljana)*, B., And. **9** (1933), nos. 1-4, p. 94-106. [In Croatian, with German summary, this article reviews contributions to geology of the Triglav Mountains, 1790-1820, focusing on the researchers located at Ljubljana, Yugoslavia.]

[1337] Ernest Faninger., "Die Entdeckung des Zoisits," *Geologiia*, **28-29** (1985-1986), p. 337-342, figs. 1-2 (in color). [On the discovery of Zoisite.]

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the mineralogical portion into Slovene,[1341] and Karla Hinterlechner brought out — — — in 1903,[1342] Leopold Poljanca authored — — — in 1909,[1343] and in 1930 Frana Dolžana published — — —.[1344]

Topographical Studies

1984 Ivan Herčko., *Minerály Slovenska*. Banská Stiavnika, Vydavatelstvo Osueta, 1984. 235 p. [Bibliography, p. 200-211.].

## 11.2.7 Northern Islands

### 11.2.7.1 Iceland (Ísland)[1345]

Topographical Studies

1801 C.F. Schumacher., *Versuch eines Verzeichnisses der in den Dänisch-Nordischen Staaten sich iindenden einfachen Mineralien*. Kopenhagen, 1801. 180 p. [An early topographical study that includes mineralogical descriptions of Norway, Faeroes, Iceland, and Greenland.].

1853 W. Sartorius von Waltekshausen., *Über die vulkanischen Gesteine in Sicilien und Island*. Göttingen, 1853. 548 p..

1853 W. Sartorius von Waltekshausen., *Geologischer Atlas von Island*. Göttingen, 1853. 65 p., 25 plates.

1907 Louis Pope Gratacap., "The minerals of Iceland," *Bulletin of the New York Mineral Club*, **1** (1907), no. 1, 9 p. [Reprinted, *The Mineral Collector*, **14** (1907), p. 46-48, 61-63, 77-80.].

1981 Volker Betz., "Famous mineral localities: Zeolites from Iceland and the Faeores," *Mineralogical Record*, **12** (1981), p. 5-26.

2002 Kristjan Saemundsson and Einar Gunnlaugsson., *Icelandic Rocks and Minerals*. Translated by Anna Yates. Reykjavík, Mál Og Menning, 2002. 234 p. [ISBN 9979321997.].

[1341] Title here ...
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[1342] Title here ...
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[1343] Title here ...
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[1345] Further historical information may be found in: Axel Garboe., *Geologiens historie i Danmark. I. Fra myte til videnskab. Fra de ældste tider til 1835 (med Norge til 1814). II. Forskere og resultater. Fra 1835 eil nutiden*. Copenhagen, C.A. Reitzels Forlag, 1959-61. 2 vols. [1]-283 p., 95 illus.; [1]-522 p., 188 illus. [Comprehensive, well illustrated history of geology in Denmark, Iceland and Norway until 1814.] • Martin Schwarzbach., "Island-200 Jahre geologischen Forschung," *Nova Acta Leopoldina*, New Series, **45** (1976), 369-380. [Recounts 200 years of geological research in Iceland.]

### 11.2.7.3 Greenland (Grønland)[1346]

Topographical Studies

1801 C.F. Schumacher., *Versuch eines Verzeichnisses der in den Dänisch-Nordischen Staaten sich iindenden einfachen Mineralien*. Kopenhagen, 1801. 180 p. [An early topographical study that includes mineralogical descriptions of Norway, Faeroes, Iceland, and Greenland.].

1878 Anonymous., *Gieseckes Mineralogiske Rejse i Grönland*. Kjøbenhavn, 1878. 399 p., maps.

1898 Gustav Flink., "En mineralogisk resa i Grönland 1897," *Ymer*, **2** (1898), p. 141-154, one map.

1900 Gustaf Flink., "Undersøgelser af mineraler fra Julianehaab indsamlede af G. Flink 1897, af G. Flink, O.B. Bøggild og Chr. Winther, med indledende bemærkninger af N.V. Ussing," *Meddelelser om Grønland. Kjøbenhavn*, **24** (1901), p. 1-213, plates I-IX (1 fold.), diagrams. [Contents : I. G. Flink., "On the minerals from Narsarsuk on the firth of Tunugdliarfik in southern Greenland".; II. O.B. Bøggild and C. Winther., "On some minerals from the nephelite-syenite at Julianehaab, Greenland (epistolite, britholite, schizolite and steenstrupite) collected by G. Flink."].

1905 Ove Balthasar Bøggild., *Mineralogia Groenlanica*. Kjøbenhavn, 1905. 644 p., map.

1953 Ove Balthasar Bøggild., *The Mineralogy Of Greenland*. Kopenhavn, 1953. [1]-442 p. [Published as: *Meddelelser Om Grønland Udgivne Af Kommissionen For Videnskabelige Undersøgelser I Grønland*, **149** (1953).].

1978 S. Karup-Møller., *The ore minerals of the Ilímaussaq intrusion their mode of occurrence and their conditions of formation*. København : Grønlands geologiske undersøgelse, 1978. 51 p., illus., maps. [Published as *Bulletin (Grønlands geologiske undersøgelse)*, no. 127.; Mineralogy of Greenland.].

1985 O.V. Petersen and K. Secher., *Grönland: Mineralien, Geologie, Geschichte*. Magma, Verlag Bode and Partner, Bochum, 1985. 83 p., illus. color.

1993 O.V. Petersen and K. Secher., "The minerals of Greenland," *Mineralogical Record*, **24** (1993), no. 2, 65 p.

2005 Ole V. Petersen and Ole Johnsen., *Mineral species first described from Greenland*. Ottawa, Mineralogical Association of Canada, 2005. viii, 184 p., illus. [Published as *The Canadian Mineralogist Special Publication*, no. **8**, the work contains much historical information in the introduction on the development of mineralogy in Greenland.].

## 11.2.8 Scandinavia

Topographical Studies

[1346] Further historical information may be found in: X. Landerer., "[Ueber die Bergwerke der Alten in Griechenland.]," *Neues Jahrbuch für Mineralogie*, **1864**, p. 45-48. • Ole V. Petersen and Ole Johnsen., *Mineral species first described from Greenland*. Ottawa, Mineralogical Association of Canada, 2005. viii, 184 p., illus. [Published as *The Canadian Mineralogist Special Publication*, no. **8**, the work contains much historical information in the introduction on the development of mineralogy in Greenland.] • Henning Sørensen., *On the history of exploration of the Ilímaussaq alkaline intrusion, South Greenland*. With 10 figures in the text and 3 appendices. C.A. Reitzels Forlag og Kommissionen for Videnskabelige Undersøgelser i Grønland, 1967. [Published as *Grønlands Geologiske Undersøgelse. Meddelelser om Grønland*, **181** 1967), no. 3, *Contribution to the Mineralogy of Ilímaussaq*, no. 3, Engelsk.]

1976 H.J. Wilke., *Mineral-Fundstellen*. Band 4, *Scandinavien*. München, Christian Weise Verlag, 1976. 270 p., illus.

## 11.2.8.1 Sweden (Sverige)[1347]

Topographical Studies

1826 Wilhelm Hisinger., *Versuch einer mineralogischen Geographie von Schweden*. Translated by F. Wöhlek. Leipzig, 1826. 250 p.
1843 Wilhelm Hisinger., *Handbok för mineraloger under resor i Sverige*. Stockholm, 1843. 194 p.
1843 Axel Erdmann., "Försök till en geognostisk-mineralogisk beskrifning öfver Tunabergs socken i Södermanland," *Svenska Vet.-Akad. Handl.*, 1843, pt. 2, 94 p., maps. Translated by F. Creplin in *Neues Jahrbuch für Mineralogie*, supplement, 1851.
1871 L.J. Igelström., *Mineralogisk Vägvisare in Wermland*. Karlstad, 1871. 46 p.
1893 H. Sjögren., "Contributions to Swedish mineralogy," *Bulletin of the Geological Institute, University of Upsala*, **1** (1893), p. 1-64; **2** (1895), p. 37-108.
1908 Gustav Flink., "Bidrag till Sveriges mineralogi," *Arkiv für Kemi, Mineralogi, Geologi*, 4 parts, 1908-17, **3** (nos. 11 & 35), **5** (no. 10), **6** (no. 21). [The series ends abruptly in the middle of the silicates and never was completed.].
1920 Gustav Flink., "Långban and its minerals," *American Mineralogist.*, **11** (1920), p. 195-199.
1921 Gustav Flink., "Lista på mineral från Långban," *Geol. För. Förh. Stockholm*, **43** (1921), p. 195-201; **44** (1922), p. 535-539.
1924 Gustav Flink., "Bidrag till Malmbergsgruvornas och Kiirunavaaras mineralogi," *Vetensk. Prakt. Undersök. Lappland*, 1924, Lapplandsgruvornas Mineralogi, no. 7, 196 p.
1937 P. Quensel., et al., "Minerals of the Varuträsk pegmatite," *Geol. För. Förh. Stockholm*, 1937-40, vols. 59-08. (A series of 37 papers.) [M.A. 6-9.].
1999 Dan Holtstam and Jörgen Langhof., *Långban: the mines, their minerals, geology and explorers*. Stockholm, Raster Förlag, Swedish Museum of Natural History; Peekskill, NY, Exclusive North American distributor, Excalibur Mineral Co., c1999. 215 p., illus. [ISBN 9187214881.].

[1347] Further historical information may be found in: A. Almquist., *Bergskollegium och bergslagsstaterna, 1637-1857. Administrativa och biografiska anteckningar*. Stockholm, P.A. Norstedt & söner, 1909. 322 p. [History of the Swedish Bergkollegium containing much otherwise unattainable biographical information.] • Nils Edelman., *Filosofer, forskare och filurer ur geologins historia*. Stockholm, 1994. 330 p., illus. [Philosophers, researchers, and rogues from geological history.] • Tore Frängsmyr., *Geologi och skapelsetro. Föteställningar om jordens historia fran Hiärne till Bergman. With an English summary*. Stockholm, Almquist und Wiksell, 1969. 379 p. [Published as: *Lychnos-Bibliotek*, no. 26. Describes the relationship between geology and religion in Sweden from Hiärne through Bergman.] • Dan Holtstam and Jörgen Langhof., *Långban: the mines, their minerals, geology and explorers*. Stockholm, Raster Förlag, Swedish Museum of Natural History; Peekskill, NY, Excalibur Mineral Co., c1999. 215 p., illus. [ISBN 9187214881.] • Sven Lindroth., *Paracelsismen i Sverige till 1600-talets mitt*. Stockholm, 1943. 540 p. [Published as: *Lychnos Bibliothek*, no. 7. Describes Paracelism in Sweden until the middle of the 17th century.] • Hugo Olsson., *Kemiens historia i Sverige intill år 1800*. Uppsala, 1971. viii, 384 p. [Publised as: *Lychnos Bibliothek*, no. 17. History of chemistry in Sweden until 1800.] • G. Regnell., "On the position of paleontology and historical geology in Sweden before 1800," *Arkiv för Mineralogi och Geologi*, **1** (1948), p. 1-64. • Nils Zenzén., "Studier i och rörande Bergskollegii mineralsamling," *Arkiv för Kemi, Mineralogi och Geologi*, **8** (1921), no. 1, p. 1-70. [Historical study of the development of the mineral collection of the Stockholm Mining College.] • *ibid.*., "Försök till historik över Cederbaumska mineral-samlingen i Oskarshamn," *Arkiv för Kemi, Mineralogi och Geologi*, **10A** (1929), no. 6, 1-98 p., 62 illus. [A history and inventory of Peter Christoffer Cederbaum's [1733-1795] collection of minerals, now at the Fredriksberg and Helgerum Estates, Småland, Sweden, including J.G. Wallerius's [1709-1785, collection bought in by Cederbaum.]

## 11.2.8.2 Finland[1348]

Topographical Studies

1820 N.G. Nordenskiöld., *Bidrag till närmare kännedom af Finlands mineralier och geognosie*. Stockholm, 1820. 107 p.
1856 A. Mouero., "Några bidrag till kännedom af Finlands mineralier," *Acta Societatis Scientiarum Fennicae*, **4** (1856), p. 579-606.
1857 S.J. Holmberg., *Mineralogischer Wegweiser durch Finnland*. Helsingfors, 1857. 76 p.
1863 N.A.E. Nordenskiöld., *Beskrifning öfver de i Finland funna mineralier*. Second edition., Helsingfors, 1863. 182 p.
1921 Aarne Laitakari., "Über die Petrographie und Mineralogie der Kalkstein-lagerstätten von Parainen (Pargas)," *Bull. Geol. Undersök. Finland*, no. 54 (1921), 114 p.
1934 Aarne Laitakari., *Geologische Bibliographie Finnlands, 1555-1933*. [1]-223 p. [Published as: *Bulletin de la Commission Géologique de Finlande*, **108** (1934).; Bibliography of Finnish geology, 1555 to 1933.].

[1348] Further historical information may be found in: Leon H. Borgström., "Geschichte der Geologie in Finnland," *Geologische Rundschau*, **32** (1942), p. 415-434. [History of geology in Finland.] • T. Enkvist., *The history of chemistry in Finland, 1828-1918*. Helsinki, 1972. 161 p., 42 illus. (portraits). • Pentti Eskolas., "Gruss an Finnlands Staatsuniversität," *Geologische Rundschau*, **31** (1940), p. 501-505. • Hans Hausen., *The history of geology and mineralogy in Finland, 1828-1918*. Helsinki, Tilgmann, 1968. 147, [1] p., illus., biblio., indexes. • O.E.A. Hjelt., *Naturalhistoriens studium vid Åbo universität*. Helsingfors, [Tidnings- & tryckeri-aktiebolagets tryckeri], 1896. 446 p. [Published as: *Skrifter utigivfna af Sveska literatursällskapet i Finland*, **32** and *Åbo Universitets Lärdomshistoria*, no. 6; History of natural history studies at Åbo University.] • Eevert Laine., "Geologischen toimikunnan syntyvaiheet 1856-1885 — Die Entstehungsphasen der Geologischen Kommission in den Jahre 1856-1885," *Finland, Geol. Tutkimuslaitos, Geotek. Julkaisuja*, no. **43** (1937), 58 p., illus. [In Finnish, this is an account of the history of the geological work in Finland that lead to the establishment of the Geological Survey of Finland.] • *ibid.*., "Malminetsinta Suomessa 1809-1884," *Finland, Geol. Tutkimuslaitos, Geotek. Julkaisuja*, no. **49** (1950), 103 p., illus. [In Finnish, this is an account of ore prospecting and exploitation in Finland, 1809-1884.] • V. Ojala and E.R. Schierz., "Finnish chemists," *Journal of Chemical Education*, **14** (1937), p. 161-165. • R. Tigerstedt., "Kemins studium vid Åbo universitet," *Skrifter utgivna av Svenska Litteratursällskapet i Finland*, **42** (1899), 210 p.

1976 H.J. Wilke., *Mineral Fundstellen*. Band 4, *Skandinavien*. München, Christian Weise Verlag, 1976. 370 p., illus.

### 11.2.8.3 Norway (Norge)[1349]

Topographical Studies

1801 C.F. Schumacher., *Versuch eines Verzeichnisses der in den Dänisch-Nordischen Staaten sich iindenden einfachen Mineralien*. Kopenhagen, 1801. 180 p. [An early topographical study that includes mineralogical descriptions of Norway, Faeroes, Iceland, and Greenland.].

1824 C.F. Naumann., *Beyträge zur Kenntniß Norwegen's, gesammelt auf Wanderungen wåhrend der Sommermonate der Jahre 1821 und 1822*. Leipzig, A. Wienbrack, 1824. 2 vols.

1948 P.C. Weibye., "Beiträge zur topographischen Mineralogie Norwegens," *Archiv für Mineralogie, Geologie. Bergbau und Hüttenkunde*, **22** (1948), no. 2, p. 465-544, illus.

1949 I. Offedal., *Översikt over Norges Mineraler*. Christiania, Oslo, Norges Geologiske Undersokelse, 1949.

1976 H.J. Wilke., *Mineral Fundstellen*. Band 4, *Skandinavien*. München, Christian Weise Verlag, 1976. 370 p., illus.

1985 Henrich Neumann. *Norges mineraler*. Trondheim, Universitetsforlaget, 1985. 278 p. Published as *Norges Geologiske Undersokelse Skrifter*; no. 68. [Bibliography of mineralogy in Norway.].

1989 T.T. Garmo., *Norsk Steinbok*. Oslo, Norwegian University Press, 1989. 2nd edition. 273 p., illus.

### 11.2.8.4 Denmark (Danmarks)[1350]

Topographical Studies

1801 C.F. Schumacher., *Versuch eines Verzeichnisses der in den Dänisch-Nordischen Staaten sich iindenden einfachen Mineralien*. Kopenhagen, 1801. 180 p. [An early topographical study that includes mineralogical descriptions of Norway, Faeroes, Iceland, and Greenland.].

1943 Ove Balthasar Bøggild., "Danmarks mineraler," *Danmarks Geol. Unders*, Series 2, **71** (1943), 68 p. (English summary, p. 60-67.).

1998 Tove Yde., *Sten og forsteninger i Danmark*. [Risskov], Klematis, 1998. 48 p., illus.

[1349] Further historical information may be found in: Axel Garboe. *Geologiens historie i Danmark. I. Fra myte til videnskab. Fra de ældste tider til 1835 (med Norge til 1814). II. Forskere og resultater. Fra 1835 eil nutiden*. Copenhagen, C.A. Reitzels Forlag, 1959-61. 2 vols. 283 p., 95 illus.; 522 p., 188 illus. [Comprehensive, well illustrated history of geology in Denmark that covers Norway until 1814.]

[1350] Further historical information may be found in: Axel Garboe., *Geologiens historie i Danmark. I. Fra myte til videnskab. Fra de ældste tider til 1835 (med Norge til 1814). II. Forskere og resultater. Fra 1835 eil nutiden*. Copenhagen, C.A. Reitzels Forlag, 1959-61. 2 vols. 283 p., 95 illus.; 522 p., 188 illus. [Comprehensive, well illustrated history of geology in Denmark.] • Leif Banke Rasmussen., *En jordisk kr° nike træk af DGU's historie 1888-1988*. København, Danmarks geologiske undersøgelse Miljøministeriet, 1988. 114 p., illus. [History of the first hundred years of the Danmarks Geologiske Undersøgelse (Danish Geological Survey). ISBN 8788640213.]

### 11.2.8.5 Faroe Islands (Færøe Islands)[1351]

Topographical Studies

1800 Jørgen Landt., *Forsøg til beskrivelse over Færøerne*. Kiøbenhavn, Trykt paa Tikjøbs forlag, hos Z. Breum, 1800. 479 p., illus., folding plates. [Early description of the natural history of the Faroe Islands.].

1801 C.F. Schumacher., *Versuch eines Verzeichnisses der in den Dänisch-Nordischen Staaten sich iindenden einfachen Mineralien*. Kopenhagen, 1801. 180 p. [An early topographical study that includes mineralogical descriptions of Norway, Faeroes, Iceland, and Greenland.].

1815 Thomas Allan., "An account of the mineralogy of the Faroe Islands," *Transactions of the Royal Society of Edinburgh*, **7** (1815), p. 229-207, map.

1880 James Geikie., "On the Geology of the Faeroe Islands," *Transactions of the Royal Society of Edinburgh*, **30** (1880-1), part 1, p. 217-269, 4 plates (including geological map).

1907 James Currie., "The mineralogy of the Færöes, arranged topographically," *Transactions of the Edinburgh Geological Society*, **9** (1907), p. 1-68, map.

1910 R. Görgey., "Beitrag zur topographischen Mineralogie der Färöer," *Neues Jahrbuch für Mineralogie*, **29** (1910), p. 269-315, map.

1947 J. Rasmussen., "Oversigt over den geologiska litteratur vedrørende Færøerne," *Meddelelser fra Dansk Geologisk Forening*, **11** (1947 for 1946), p. 66-96. [An overview of the geological literature pertaining to the Faeroe Islands, together with a useful biographical glossary of the most important researchers.].

1981 Volker Betz., "Famous mineral localities: Zeolites from Iceland and the Faeores," *Mineralogical Record*, **12** (1981), p. 5-26.

## 11.2.9 Eastern Mediterranean

### 11.2.9.1 Greece ('Ελλασ)[1352]

Topographical Studies

1878 André Cordella., *La Grèce sous le rapport géologique et minéralogique*. Paris, Impr. de A. Parent, 1878. [4], 188 p., illus., folding plate. [Mineralogical study of Greece. Published as part of Greece's Commission centrale pour l'exposition universelle de Paris, 1878., Paris. Exposition universelle, 1878.].

1883 F. Toula., "Materialien zu einer Geologie der Balkanhalbinsel," *Jahrbuch der Geologischen Bundesanstalt*, **33** (1883), p. 61-114. [A bibliography of 186 titles are listed chronologically, 1828-1883. It lists books related to the Balkans.].

[1351] Further historical information may be found in: Axel Garboe., *Geologiens historie i Danmark. I. Fra myte til videnskab. Fra de ældste tider til 1835 (med Norge til 1814). II. Forskere og resultater. Fra 1835 eil nutiden*. Copenhagen, C.A. Reitzels Forlag, 1959-61. 2 vols. 283 p., 95 illus.; 522 p., 188 illus. [Comprehensive, well illustrated history of geology in Denmark.] • J. Rasmussen., "Oversigt over den geologiska litteratur vedrørende Færøerne," *Meddelelser fra Dansk Geologisk Forening*, **11** (1947 for 1946), p. 66-96. [An overview of the geological literature pertaining to the Faeroe Islands, together with a useful biographical glossary of the most important researchers.]

[1352] Further historical information may be found in: Apostol Keramitčiev., *Staroto rudarstvo i metalurgija na Makedonija* [Ancienne exploitation des mines et la métallurgie de la Macédoine]. 1977. 54 p., illus. [History of the mines and mineral resources of Greece.]

1929 D.A. Wray., "Greece: Its geology and mineral resources," *Mining Magazine*, London, **40** (1929), p. 9-17, 85-90, 148-153.
1994 Anonymous., "Der Bergbau und die Mineralien von Laurion, Griechenland," *Emserhefte*, **2-94**, Halten, Germany, Bode Verlad Gmbh., 1994. 80 p., illus.
1996 P. Gelaude, P. van Kalmthout, and C. Rewitzer., *Laurion - The minerals in the ancient slags*. The Netherlands, Published by Janssen Print, 1996. 195 p., color illus., maps, diagrams.

### 11.2.9.2 Cyprus[1353]

Topographical Studies

1862 Albert Gaudry., *Géologie de l'ile de Chypre*. Paris, Au local de la Société, 1862. p. [149]-314, illus., 2 plates, map. [Geology of Cyprus.].
1905 P. Gennadius., *Cyprus: mineral substances utilized in the arts*. Compiled from A. Gaudry's Geologie de l'ile de Chypre and other sources. Nicosia, 1905. 19 p.
1922 C.G. Cullis and A.B. Edge., *Report on the cupriferous deposits of Cyprus*. London, 1922. 48 p. [M.A. 2-549.].
1963 G. Elliott and R. Dutton., *Know your rocks: an introduction to geology in Cyprus*. [Cyprus : s.n., 1963?]. 186 p., illus.

## 11.3 Asia

## 11.3.1 Far East

### 11.3.1.1 China[1354]

Topographical Studies

1818 L. Pansner., "Beiträge zu einem Handbuch der Mineralogie des Chinesischen Reichs und einiger angrenzenden Länder," *Taschenbuch für Mineralogie* (Leonhard's), **12** (1818), p. 128-132, 363-420.
1918 William Frederick Collins., *Mineral enterprise in China*. London, W. Heinemann, [1918]. xi, [1], 308 p., maps (partly folding). [Mines and mineral resources of China.].
1930 B.P. Torgasheff., *The Mineral Industry of the Far East*. Shanghai, 1930. 512 p.
1946 T.C. Tseng., *Bibliography of Chinese geology. Bibliography of geology and allied sciences of Tibet and regions to the west of the Chinshachiang*. Nanking, National Geological Survey of China, 1946. viii, 114 p. [Bibliography of the geology of China and Tibet.].
1980 Ren Kai-wen., *Minerals in China*. Museum of Geology, Ministry of Geology, Shanghai Scientific and Technical Publishers, Shanghai, 1980. 164 p., illus., color.
1986 Zunyi Yang, et al., *The geology of China*. Oxford, Clarendon Press; New York, Oxford University Press, 1986. x, 303 p., [24] p. of plates. [Published as *Oxford Monographs on Geology and Geophysics*, **3**, this work treats the geology, mines and mineral resources of China.].
1986 P.C. Keller and Wang Fuquaw., "A survey of the gemstone resources of China," *Gems and Gemology*, **22** (1986), p. 3-13.
1988 Anonymous., "New minerals discovered in China, 1958-1987," *Yanshi Kuangwuxue Zashi*, **7** (1988), p. 89-93, illus. [in Chinese].
1990 Liu Nailong., *Mineral deposits of China*. Edited by the Editorial Committee of the Mineral Deposits of China. Beijing, China, Geological Publishing House, 1990- . 5 vols. [A translation from the Chinese of *Chung-kuo kúang chúang*, that describes the mines and mineral resources of China.; ISBN 7116006885.].

### 11.3.1.2 Japan[1355]

[1353] Further historical information may be found in: Pantelēs Varnavas., *Ta metalleia tēs Kyprou: historikē anadromē*. [Nicosia, Cyprus] PEO, 1993. 127 p., illus., map. [History of the mines and mineral resources of Cyprus. The text in Greek with summaries in English and Turkish.; ISBN 9963767729.]

[1354] Further historical information may be found in: D.P. Agrawal., *Ancient metal technology and archaeology of South Asia: a Pan-Asian perspective*. New Delhi, Aryan Books International, 2000. xvi, 254 p., [32] p. of plates, illus., map. [History of metallurgy in South Asia.; ISBN 8173051771.] • Fa-Ti Fan., "Victorian naturalists in China: science and informal empire," *The British Journal for the History of Science*, **36** (2003), p. 1-26. • Berhold Ottens., "Mining in China," *Mineralogical Record*, **36** (2005), p. 4-11, illus. • Hungzhen Wang, Hsiang-jung Hsia, et al., *A brief history of geology in China*. Committee on History of Geology., Chung-kuo ti chih ta hsüeh. Research Section on History of Geology. Beijing, The University, 1989. 75, 9 p. Includes bibliographical references. [A history of geology in China.] • Tsui-Hua Yang., "The development of geology in Republican China, 1912-1937" (pp. 221-244) in: Cheng-Hung Lin and Daiwie Fu, eds., *Philosophy and Conceptual History of Science in Taiwan*. Dordrecht, Kluwer Academic Publishers, 1993. • Dazheng Zhang and Carol Faul., "A history of geology and geological eductation in China (to 1949)," *Earth Sciences History*, **7** (1988), p. 27-32. [The bibliography lists references in both English and Chinese.]

[1355] Further historical information may be found in: F.A. Bather., "Natural science in Japan," *Natural Science*, **4** (1894), pp. 19-26, 98-111 and 183-193. [Pages 105-111 concerns geology and mineralogy.] • Bureau of Mines., *Mining in Japan—past and present* (Department of Agriculture and Commerce of Japan). Tokyo, 1909. 322 p. • Zyunpei Harada., "Mineralogy in Japan since the beginning of the Meiji Era," *Tōkyō Chigaku Kyōkai hōkōku* (Journal of the Tokyo Geographical Society), **63** (1954), no. 3 (693), p. 166-75. [In Japanese, this article covers the history of mineralogy in Japan from 1868 to 1912.] • Hirokazu Hase and Kisaburo Kodama., "The changing mission of the Geological Survey of Japan in a changing world" (pp. 187-196) in: Shih-jung Mei, Hongzhen Wang, Borming Jahn, eds., *Proceedings of the 30th International Geological Congress*. Beijing, China, 4-14 August 1996. • Junji Itoigawa., *Nihon rettō no rekishi sono tanjō to hensen*. Tōkyō, Kōdansha, Shōwa 48 [1973]. 222 p., illus. [Published as *Kōdansha gendai shinsho*, no. 326; In Japanese, this is a history of geology in Japan]. • Kotora Jimbō., "Waga Kuni ni okeru Kōbutsugaku no Rekishi" [History of mineralogy in Japan], *Chishitsugaku zasshi* (*Journal of the Geological Society of Japan*), **10** (1903), 442-50. [in Japanese, this appears to give a history of the science in Japan, together with a list of published books.] • J. Maclean., "The introduction of books and scientific instruments into Japan, 1712-1854," *Japanese Studies in the History of Science*, **13** (1974), 9-68. • *ibid.*, "Natural science in Japan, I: Before 1830," *Annals of Science*, **30** (1975), p. 257-298. • *ibid.*, "Natural science in Japan from 1828 to 1849," *Janus: Revue Internationale de l'Historie des Sciences, de la Médecine et de la Technique*, **62** (1975), p. 51-78. • Tadashi Sato., "Historical review of geological sciences in

Topographical Studies

1878 A.J.C. Geerts, *Les Produits de la Nature Japonaise et Chinoise*. Yokohama, 1878-83. 2 parts. [8], xi, [1], 294, [2] p., 15 plates.; [4], [295]-662 p., 8 plates. [Originally planned as a comprehensive study of the nature of Japan and China, only the portion dealing with minerals ever appeared.].

1904 Tsunashirō Wada., *Minerals of Japan*. Tokyo, 1904. [4], vii, [1], 144, [2] p., 30 (i.e., 31) plates.

1935 Tsunashirō Wada and T. Ito., *Beiträge zur Mineralogie von Japan*. Tokyo, Mineral Inst., 1935-37. 2 vols., 256 p.; 168 p., illus., with English summaries.

1937 T. Ito., *Japanese Minerals in Pictures*. Tokyo, 1937. 4 vols., illus.

1944 Y. Okamoto., *Minerals of Fukuoka Prefecture*. Tokyo, Japanese Mineral Hobby Association, 1944. 208 p., illus., English index. [In Japanese.].

1970 M. Namu., *Introduction to Japanese Minerals*. Editorial Committee, Geological Survey of Japan, Organizing Committee, IMA-IAGOD Meeting 1970, 208 p., illus. color.

1971 H. Shirozo, et al., "Ko collection of minerals," *Department of Geology, Kyushu University*, **11** (1971), p. 147-208, illus. [In Japanese with English summary.].

1977 F.I. Kai., "Mineral list of Fukuoka Prefecture," *Geoscience Magazine*, **20** (1977), no. 4-6, p. 121-148, illus. [In Japanese.].

1980 M. Nambu and K. Tanida., "Mineral species from northeast part of Japan," *Journal of the Japanese Association of Mineralogists, Petrologists and Economic Geologists, Special Issue*, **2** (1980), p. 123-132. [In Japanese with English Summary.].

1983 Phil Scalisi and D. Cook., *Classic Mineral Localities of the World: Asia and Australia*. New York, Van Nostrand Reinhold, 1983. 226 p., illus.

2002 Satoshi Matsubara., *The mineral species of Japan*. Fifth edition. Tokyo, 2002. 76 p. [Lists all of the minerals found in Japan, arranged alphabetically. Included for each listing is the name of the mineral, chemical composition, Japanese name for the mineral, and the crystal system.].

### 11.3.1.3 Korea (Chosen)[1356]

Topographical Studies

19— Senseido Company., *Minerals from Korea*. Tokio, Korea Geological Survey, 19—. 357 p., illus. [In Japanese.].

1915 N. Fukuchi., "Mineralogy of Chosen," *Beitrage zur Mineralogie von Japan*, no. 5 (1915), p. 207-227.

1923 Anonymous., *Minerals of Chosen*. Published as *Korea Mineral Survey Bulletin*, no. 2 (1923), 104 p.

1960 H. Tsuda., *Minerals of Korea*. U.S. Army, Corps of Engineers, Far East, Pacific Surveys Report **659** (1960), 64 p.

1962 David Gallagher, et al., *Mineral resources of Korea*. [Washington : U.S. Geological Survey], 1962. 4 vols. [Covers the geology, mines and mineral resources of Korea.].

1985 K. Hefendehl., "Mineralien aus Südkorea," *Lapis*, **10** (1985), no. 9, p. 21-30.

### 11.3.1.4 Taiwan[1357]

Topographical Studies

1912 Y. Okamoto., "Minerals of Taiwan," *Beiträge zur Mineralogie von Japan*, **4** (1912), p. 157-188. [Translation of a 1911 report in Japanese, Taihoku, 128 p.].

## 11.3.2 Central Asia[1358]

### 11.3.2.1 Siberia

Topographical Studies

1992 Aleksei Andriianovich Konev., *Prikladnaia mineralogiia Vostochnoi Sibiri*. Irkutsk, Izd-vo Irkutskogo un-ta, 1992. 250, [22] p., illus. [Mines and mineral resources of eastern Siberia.].

### 11.3.2.2 Transcaucausia[1359]

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Japan," *Episodes*, **14** (1991), no. 3, p. 187-9, portrait (of author). • Eikoh Shimao., "Some aspects of Japanese science, 1868-1945", *Annals of Science*, **46** (1989), p. 69-91. [A brief history of Japanese science since the beginning of Japan as a modern state]. • Mitsutarō Shirai., *Nihon hakubutsugaku nenpyō*. Tōkyō, Ōokayama Shoten, Shōwa 18 [1943]. 437 p., illus., portraits. [Written in Japanese this book contains among other natural history subjects, a chronology of the history of mineralogy in Japan.] • Naoki Tanaka., *Kōzan hattatsushi Nōshōmushō Kōzankyoku hen kaidai Tanaka Naoki*. Tōkyō, Hara Shobō, 1992. [1], 4, 583, [1] p., illus. [Written in Japanese and originally published in 1900, this is a reprint of a history of mining and mineral resources in Japan.; ISBN 4562022647] • Masuzō Ueno., *Nihon hakubutsugakushi*. Tōkyō, Heibonsha, Shōwa, 48 [1973]. 680, 73 p., illus. [History of natural history in Japan, with a long bibliography, p. 161-183.] • Mitsuaki Watanabe., "[Chronological table of the geology and mineralogy of modern Japan]," *Kagakusi kenkyū. Nihon Kagakushi Gakkai. Journal of the History of Science of Japan*, **25** (1953), p. 17-22. [In Japanese, entry taken from *ISIS Cumulative Bibliography*, **3**, p. 233a.]

[1356] Further historical information may be found in: William Frederick Collins., "Mining in Korea (Chosen)," (pp. 136-143) in: W.F. Collins., *Mineral enterprise in China*. London, W. Heinemann, [1918]. xi, [1], 308 p., maps (partly folding). [Korea is included in this mines and mineral resources of China.]

[1357] Further historical information may be found in: Tsui-Hua Yang., "The development of geology in Republican China, 1912-1937" (pp. 221-244) in: Cheng-Hung Lin and Daiwie Fu, eds., *Philosophy and Conceptual History of Science in Taiwan*. Kluwer Academic Publishers, 1993.

[1358] Further historical information may be found in: Ahmad Hasan Dani., et al., *History of civilizations of central Asia*. Delhi, Motilal Banarsidass Publishers, 1999. 4 vols. [Published as a project of UNESCO, the fourth volume describes "The age of achievement AD 750 to the end of the fifteenth century". There in part 2, chap. 8 is, "Geodesy, geology and mineralogy. Geography and cartography. The Silk Route across Central Asia: Part One, Geodesy and mineralogy, Geography and cartography" by S. Maqbul Ahmad.]

[1359] Further historical information may be found in: Mïansarov, Mikhail Misropovich., *Bibliographia caucasica et transcaucasica. Essai d'une bibliographie systématique relative au Caucase, à la Transcaucasie et aux populations de ces contrées*. St. Pétersbourg, Impr. de J. Bakst et de Hohenfelden & comp., 1874-1876. 2 parts in one volume. [6], xlii, 804 p. [Contents: Sect. I. La nature: I. Géodésie. II. Cartographie. III. Géographie physique. IV. Géologie. V. Botanique. VI. Eaux minérales. VII. Métórolgie. VIII. Médicine indigène.–sect. II. Lhomme et la nature: I. Ethnographie. II. Voyages. III. Antiquités. IV. Numinsmatique. V. Histoire.]

## 11.3.7 Subcontinent

### 11.3.7.1 India[1360]

Topographical Studies

1887 F.R. Mallet., *A manual of the geology of India. Part 4, Mineralogy*. Calcutta, Geological Survey of India, 1887. 190 p.

1889 Anonymous., "Provisional index of the local distribution of important minerals, miscellaneous minerals, gemstone and quarry stones in the Indian Empire," *Records of the Geological Survey of India*, **22** (1889), p. 237-286; **23** (1890),, p. 120-203.

1942 B.R. Rau., "Mineral resources of Mysore," *Quarterly Journal Geology, Mining, and Metall. Society India*, **14** (1942), p. 157-184.

1966 D.N. Wadia., *Minerals of India*. New Delhi, National Book Trust, 1966.

### 11.3.7.2 Sri Lanka (Ceylon)

Topographical Studies

1888 A.M. Ferguson and J. Ferguson., *All About Gold, Gems and Pearls in Ceylon and Southern India*. Second edition. Colombo, London, 1888. 428 p.

1897 F.H. Modder., "A geological and minerological sketch of the north western province of Ceylon," *Jour, of Cey. Br. Roy. Asia. Soc.*, **15** (1897).

1900 F. Gruenling., "[Over the mineral sources of Ceylon]," *Zeitschrift für Krystallographie*, **33** (1900), p. 209-223.

1905 A.K. Coomaraswamy., "The rocks and minerals of Ceylon," *Spolia Zeylanica*, **3** (1905), p. 50-66.

1967 H.S. Guaratne., *Rocks and Minerals of Ceylon*. Colombo, 1967. 58 p., illus, [Published as *Ceylon Museum Handbook Series*, no. 1.].

1990 J.W. Herath., *Sri Lanka Minerals A Descriptive Catalogue*. New Delhi, Ceramic Research and Development Centre (CRDC), c1990. ix, 97 p., tables.

### 11.3.7.3 Nepal

Topographical Studies

1995 Chandra K. Sharma., *Mineral resources of Nepal*. Kathmandu, Nepal, Sangeeta Sharma, 1995. 142 p., illus.

2004 P.R. Joshi., *Mineral resources of Nepal*. Kathmandu, His Majestry's Govt. of Nepal, Ministry of Industry, Commerce, and Supplies, Dept. of Mines and Geology, 2004. 154 p., colored illus., maps.

### 11.3.7.4 Pakistan[1361]

The country of Pakistan, which is rich in minerals, became a country separate from India in 1948, and is, therefore, past the cut off date for inclusion in the regional histories. The old history of mineralogy in this region is included in the sections on Ancient India (§2.9) and India (§11.3.7.1). This section headed, Pakistan, is included simply as a place holder for the few historical references that have turned up during other literature searches, and a place to put topographical studies.

Topographical Studies

1954 A.M. Heron., *Directory of Economic Minerals of Pakistan*. Records of the Geological Survey of Pakistan, **7** (1954).

1974 Y. Matsumoto., "List of minerals from the Tirich Mir and adjacent regions, the Hindu Kush Range, Pakistan," *Geoscience Magazine*, **25** (1974), p. 65-76, illus. [In Japanese with English summary.].

## 11.3.8 Southeast Asia

### 11.3.8.1 Burma

Topographical Studies

1860 Francis Mason., *The Natural Productions of Burma or Notes on the Fauna, Flora, and Minerals*. Burma, Moulmain, 1860. 2 vols.

1882 Francis Mason and William Theobald., *Burma, its people and productions, or, Notes on the fauna, flora, and minerals of Tenasserim, Pegu, and Burma*. Third edition. Hertford, Published by order of the Chief Commissioner of British Burma by S. Austin, 1882-1883. 2 vols. [Contents: v. 1. Geology, mineralogy, and zoology; v. 2. Botany.].

1934 H.L. Chhibber., *The Mineral Resources of Burma*. London, 1934. 335 p., map.

### 11.3.8.1 Cambodia

Topographical Studies

1957 E. Saurin., "Some gem occurrences in Cambodia," *Rocks and Minerals*, **32** (1957), p. 397-398.

### 11.3.8.1 Indonesia[1362]

Topographical Studies

1826 T. Horsfield., "On the mineralogy of Java," *Verh. Bat Genootschap Kunst, en Wetenschap*, Batavia, **8** (1826), p. 141-312.

1890 D. de Loos., *Gesteenten en Mineralien van Nederlandsch Oost-Indië*. Haarlem, Nederl. Maatschappij, Kolonial Museum, 1890-1898, nos. 1-4.

1911 J.S. Geikie., "A list of Sarawak minerals," *Sarawak Museum Journal*, **1** (1911), p. 194-201.

1912 G.P. Chernik., "Sur la minéralogie de l'île de Borneo," *Trav. Mus. Géol. Acad. Sci.*, St. Petersbourg, **6** (1912), 49-96. [in Russian].

1912 R.D.M. Verbeek., "Opgave van geschritten over géologie en mijnbouw van Nederlandsch Oost-Indië,"

[1360] Further historical information may be found in: Cyril S. Fox., "The Geological Survey of India, 1846 to 1947," *Nature*, **160** (1947), no. 4078, p. 889-891. • K.S. Murty., "Geological sciences in India in 18th-19th century," *Indian Journal for the History of Science*, **17** (1982), p. 114-131. • Satpal Sangwan., "Reordering the earth: the emergence of geology as a scientific discipline in colonial India," *Earth Science History*, **12** (1993), no. 2, p. 224-233.

[1361] Further historical information may be found in: H. Crookshank., "The Geological Survey of Pakistan," (Presidential address), *Pakistan Scientific Confrence*, 4th Proceedings, 1952, part 2, p. 129-144. [An outline of the development of the Geological Survey of Pakistan, founded in 1947, with reports of the results of geological research and mineral investigations carried out.] • A.M. Heron., "History of the Geological Survey in Pakistan," *Records of the Pakistan Geological Survey*, **4** (1951?), pt. 2, 44 p. [Includes an extensive bibliography.]

[1362] Further historical information may be found in: Reinout Willem Van Bemmelen. "Geschiedenis van het geologisch onderzoek in Indonesië," *Chronica Naturae*, **106** (1950), Aff. 5, p. 177-184. [Outlines the history of geological research in Indonesia.]

*Verh. Geol. Mijn. Genootschap Nederland en Kolonie, Geol. Series*, **1** (1912), p. 31-248; also **1** (1915), p. 369-376.

### 11.3.8.1 Laos

### 11.3.8.1 Malaysia

Topographical Studies

1925 E.S. Willbourn., "A list of minerals found in British Malaya," *Journal Malayan Branch Royal Asiatic Society*, **3** (1925), part 3, p. 57-100.

### 11.3.8.1 Philippines[1363]

Topographical Studies

1914 W.D. Smith., F.T. Eddingfield, and P.R. Fanning., "Preliminary check list of Philippine minerals," *Mineral Resources of the Philippine Islands for 1913*, **1914**, p. 56-71.
1924 W.D. Smith., *Geology and Mineral Resources of the Philippine Islands*. Manila, 1924. 559 p., illus.

### 11.3.8.1 Thailand

Topographical Studies

1902 Anonymous., "Les Mines de Siarn," *Bull. Musee Cornera, Bruzelles*, **1775** (1902).
1951 E.D. Brown, *et al.*, *Geological Reconnaissance of the Mineral Deposits of Thailand*. U.S. Geological Survey, **984** (1951), 183 p., illus.

### 11.3.8.1 Vietnam

Topographical Studies

1909 Gaston Dupouy., *Contribution a l'étude de la minéralogie de l'Indochine; minerais et minéraux du Tonkin*. Paris, Emile Larose, 1909. 163 p. [Published as a *Contribution á l'étude de la Minéralogie de l'Indo-Chine*.].
1913 Gaston Dupouy., *Etudes Minéralogiques sur l'Indochine Française*. Paris, É. Larose, 1913. 438 p., maps. [Covers the mines and mineral resourcesof Indochina.].
1989 C. Premoli., "Vietnamese metallic mineral resources," *Engineer and Mining Journal*, **190** (1989), no. 12, p. 31-35.

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## 11.7 Australasia

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Topographical Studies

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Topographical Studies

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[1390] Further historical information may be found in: R.N. Brothers, ed., *University of Auckland: History of geology, 1883–1983*. Auckland, 1983. • M.P. Burton., *The New Zealand Geological Survey, 1865–1965*. Wellington, 1965. • A.R. Lillie., "A century of geological research in the Auckland province," *New Zealand, Journal of Geology and Geophysics*, **2** (1959), no. 5, p. 920-943. [Reviews the history of geological research of Auckland province, New Zealand, from the first investigations of F. von Hochstetter in 1859. It includes an extensive bibliography.]

12.0 Collectors & Dealers

## 12.1 Collectors[1391]

**REWORK:** Minerals, together with other objects of nature, have for a very long time been the objects of appreciation by man.

## 12.2 Dealers[1392]

**REWORK:** In 1926 the oldest mineral firm still in existance was the official mineral store of the Bergakademie in Freiberg, which opened in the eighteenth century during the lifetime of Werner. Its purpose was to sell the duplicate specimens from collections they acquired as well as newly discovered material. Soon thereafter the "Mineralien Comptoir" developed in Heidelberg, which was however a completely private enterprise, operated at the beginning by Moldenhauer. Seifert opened his business in Teplitz during the early 19th century, and had an important trade in Bohemian minerals. In 1833, Franz Krantz established his shop in Berlin, which was later moved to Bonn, where it still operates. Elsewhere in the 19th century, the mineral dealing firm of Grebel & Wendler opened in Geneva, Stuer in Paris, and several others in Vienna and London. In 1888, in anticipation of the World's Fair to be held in Paris the next year, Albert E. Foote opened a branch of his successful

[1391] Further historical information may be found in: Wendell E. Wilson., "The history of mineral collecting 1530-1799. With notes on twelve hundred early mineral collectors," *Mineralogical Record*, **25** (1994), no. 6, 264 p., illus.

[1392] Further historical information may be found in: *American mineral guide to notable collecting areas and directory of American mineral and gem collectors and collections. Together with a dealers' section listing those substantial firms supplying the needs of the mineralogist*. Seattle, Washington, Western Mineral Exchange, 1941. [8], [1]-65, [19] p. [Second edition, 1948, [6], [1]-84, [62] p.] • Groth, *Entwicklungsgeschichte der mineralogischen Wissenschaften*, 1926, ??-??. • Wilson., *History of mineral collecting*, 1994.

Philadelphia shop, which had opened during the Centennial Celebration of the United States in 1876 in that city. In North America, where during the last part of the nineteenth century interest in collecting minerals increased tremendously, a large number of new companies developed. These may be traced through their advertisements that appeared in in the journals of the day, most notably the *Mineral Collector* and the *American Mineralogist*.

### 12.3 Collections[1393]

**REWORK:** Numerous collections of minerals have been since the seventeenth century built up by institutions and state operated museums. These collections exist around the world. These repositories are a legacy of mineral history, and their specimens, from localities long ago exhausted are amazing creations.

## 12.4 The Golden Age (1876–1909)

**REWORK:** The three decades flanked by the Centennial Celebration of the United States in 1876 and the demise of both the Foote Mineral Company and the periodical the *Mineral Collector* may justifiably be called "The Golden Age" of mineral collecting. In the United States and other countries around the world the availability of mineral specimens of exceptional quality at reasonable prices was unparalleled. The great mines of the classic localities of Bisbee, Butte, Sterling Hill, Franklin, Broken Hill, Tsumeb, Japan, China were first opened and the oxide zones mined.

### 12.9.1 Austria (Österreich)[1394]

### 12.9.1 Belgium[1395]

### 12.9.1 Denmark[1396]

### 12.9.1 England[1397]

### 12.9.1 France[1398]

### 12.9.1 Hungary[1399]

### 12.9.1 Italy[1400]

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[1394] Further historical information may be found in: Leopold Josef Fitzinger., "Geschichte des k.k. Hof-Naturalien-Cabinetes in Wien," *Sitzungsberichte der kaiserlichen Akademie der Wissenschaften. Mathematisch-Naturwissenschaftliche Klasse*, **28** (1881), p. 279-342. • Marlies Raffler., "Zur Geschichte mineralogischer Sammlungen in Österreich und Ungarn," *Der Anschnitt: Zeitschrift für Kunst und Kultur im Bergbau*, **48** (1996), no. 1, p. 28-34.

[1395] Further historical information may be found in: Donnay, J.D.H., "The destruction of the Liége Museum," *American Mineralogist*, **30** (1945), nos. 1-2, p. 81-83. [The whole Mineralogical Museum of the University o f Liége, Belgium, together with other buildings were burned as the Germans retreated.]

[1396] Further historical information may be found in: Karen Callisen., "Til Mineralogisk Museum historie," *Meddelelser fra Dansk Geologisk Forening*, **10** (1945), Heft 5, p. 507-531, illus. [Notes on the history of the Danish Mineralogical Museum.]

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[1398] Further historical information may be found in: Y. Laissus., "Les cabinets d'histoire naturelle" (pp. 659-712), in: R. Taton, ed., *Enseignement et diffusion des sciences en France au XVIIIe siecle*. Paris, Hermann, [1964]. • E. Lamy., *Les cabinets d'histoire naturelle en France au XVIIIe siècle et le cabinet du roi (1635-1793)*. Paris, 1930. 58 p. • A. Schnapper., *Collections et collectionneurs dans la France du XVIIème siècle*. Tome I: Le géant, la licorne et la tulipe. Histoire et histoire naturelle. Tome II: Curieux du grand-siècle. Oeuvres d'art. Paris, Flammarion, 1988-94. 2 vols. 415 p., 72 illus.; 576 p., 138 illus. [History of collectors and collections in 17th century France.] • J. Simon., "Mineralogy and mineral collections in 18th-century France," *Endeavour*, **26** (2002), no. 4, p. 132-136.

[1399] Further historical information may be found in: Marlies Raffler., "Zur Geschichte mineralogischer Sammlungen in Österreich und Ungarn," *Der Anschnitt: Zeitschrift für Kunst und Kultur im Bergbau*, **48** (1996), no. 1, p. 28-34.

[1400] Further historical information may be found in: De Bellis, N., "Ordine e reperibilità degli oggetti nelle collezioni mineralogiche di Ulisse Aldrovandi (1522-1605)," *Museologia scientifica*, **14** (1997), no. 2, .279-297. • Callegari, A., "Cenni sul Museo mineralogico dell'Università di Pavia," *Museologia scientifica*, **14** (1997), no. 1, 21-27. • Ghiara, M.R., "Il Real Museo mineralogico [dell'Università Federico II di Napoli]," *Annali di storia delle università Italiane*, **1** (1997), 203-209. • D'Amico, C., "Il Museo di mineralogia L. Bombicci," *I luoghi del conoscere* p. 216-225. • Brogiato, C., "Museo di mineralogia e petrologia," *I musei, le collezioni scientifiche e le sezioni antiche delle biblioteche*, p. 41-48.

**12.9.1 Russia**

**12.9.1 Sweden**[1401]

**12.9.1 United States**[1402]

## 13.0 Instruction

**REWORK:** Various schools were set up to instruct students in mineralogy, mining, metallurgy, geology, and related studies. Additional societies and their respective journals were used to disperse knowledge about minerals. To help promote the studies, textbooks designed to take the beginner through the mineralogical science study were prepared and published.

Great Britain .... [1403]

Oxford... [1404]

### United States

USA Another reference....[1405]

USA Another reference....[1406]

USA Another reference....[1407]

### Russia

St Petersburg ...[1408]

### Germany

GERMANY Reference....[1409]

GERMANY University of Giessen (Germany)...[1410]

### France

FRANCE Paris School of Mines...[1411]

FRANCE Reference....[1412]

### Spain

SPAIN Spanish School of Mines....[1413]

Reference... [1414]

[1401] Further historical information may be found in: Einar Lönnberg., *Naturhistoriska riksmuseets historia*. Dess uppkomst och utveckling. Stockholm 1916. [4], 290 p., 9 plates. [Contains the essays "royal Vetenskapsakademiens naturaliekabinett 1739-1819", "Riksmuseum 1819-1841", "Riksmuseets general affairs 1841-1916" and "Riksmuseets vertebratafdelning 1841-1916" of Einar Lönnberg, "Riksmuseets botanic af division" of Carl Lindman, "Riksmuseets mineralogical af division" of Hjalmar Sjögren, "Riksmuseets entomologiska af division" of Yngve Sjöstedt, "Riksmuseets evertebratafdelning" of Hjalmar Théel, "Riksmuseets paleozoologiska af division" of Gerhard Holm, "Riksmuseets paleobotaniska af division" of A.G. Nathorst and "Riksmuseets new buildings" of A. Anderberg.] • Nils Zenzén., "Studier i och rörande Bergskollegii mineralsamling," *Arkiv för Kemi, Mineralogi och Geologi*, **8** (1921), no. 1, 1-70. [Historical study of the development of the mineral collection of the Stockholm Mining College.] • *ibid.*, "Försök till historik över Cederbaumska mineral-samlingen i Oskarshamn," *Arkiv för Kemi, Mineralogi och Geologi*, **10A** (1929), no. 6, 1-98 p., 62 illus.

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[1403] M.M. Julian., "Crystallography at the Royal Institution," *Chemistry in Britain*, **22** (1986), 729-732. [Structural organic chemistry flourished at the Royal Institution under the guidance of its director, Sir William Henry Bragg (1862-1942). Five scientists who worked at the Royal Institution are discussed.]

[1404] W.J. Sollas., *The age of the earth*. London, 1901. [i]-xvi, [1]-328 p. [Contains a chapter on the influence of Oxford on British geology.]

[1405] Robert Rakes Shrock., *Geology at MIT, 1865-1965: a history of the first hundred years of geology at the Massachusetts Institute of Technology*. Cambridge, MA.; London, MIT Press, 1977. 2 vols.

[1406] Katherine Greacen Nelson., "One hundred years of earth science at Milwaukee-Donner College," *Wisconsin Academy of Science, Transactions*, **42** (1953), p. 143-147.

[1407] Charles Palache., "Chap. 21, Mineralogy, 1869-1928," (p. 332-337), in: S.E. Morrision, ed., *The Development of Harvard University, 1869-1929*. Cambridge, MA., Harvard University Press, 1930.

[1408] D.P. Grigorev., "[175 Year History of the Mining Institute of Leningrad]," *Memoires, All-Union Mineralogical Society* (in Russian), r**77** (1948), no. 3, 177-184, 2 plates. [Outlines the 175 year history of the Mining Institute of St. Petersburg, Russia.]

[1409] Karl A. von Zittel., "History of instruction in geology and palaeontology in German Universities. Translated by Charles R. Eastman," *American Geologist*, **4** (1894), no. 3, p. 179-185.

[1410] Reinhard Brauns., "Entwicklung des mineralogischen Unterrichts an der Universität Giessen," in: *Akademische Festrede zur Feier des Jahresfestes der Grossherzoglich Hessischen Ludwigs Universität am 1. Juli 1904*. Giessen, 1904.

[1411] L. Aguillon., "L'École des mines de Paris-notice historique," *Annales de Mines*, 8th Series, **15** (1889), 433-686. [History of the Paris School of Mines.]

[1412] Émile Haug., "La chaire de géologie à la Sorbonne," *Rev. gén. Sci.*, 30 September 1904, fide Pruvost, 1951. 111 p.

[1413] Eugenio Maffei., *Centenario de la Escuela de Minas, 1777-1877*. Madrid, M. Tello, 1877. viii. 300 p. [Centenary history of the Spanish School of Mines.]

[1414] Max Semper., "Bemerkungen über Geschichte der Geologie und daraus resultierende Lehren," *Geologische Rundschau*, **2** (1911), p. 263-277.

References .... [1415]
References .... [1416]

## 13.1 Mining Academies[1417]

**REWORK:** The first mining academy was established in 17— Ekteberg? in the foothills of the Urals of western Russia. It was a shortlived institute lasting only a few years, but its purpose was to instruct its students in the techniques of mining and metallurgy.[1418]

Through the long tradition of mining in Germany particularly in the area between Saxony and Bohemia, it was a logical location to establish a school of mining. The Bergakademie (Mining Academy) of Freiberg was founded in 1765 by the Elector of Saxony, during a period after the Seven Years War (1756-1763) when the demand for the silver produced in Saxony was rapidly increasing and an improvement of the methods used for the exploitation of the mines was greatly needed. The high standard of teaching in the school is shown by the fact that Christlieb Ehregott Gellert [1713-1795] was appointed as the first professor of chemical metallurgy in the Bergakademie.

Although some type of organized teaching of mining occurred in Austria in 1761 or 1762, it is more widely accepted that the first Austrian-Hungarian mining academy was officially established in Schemnitz (now Banska Stiavnica in Slovakia) in 1770, where (as in Freiberg) a tradition of private teaching had already existed since about 1735.[1419] Also a chair of chemistry and metallurgy was established there by the imperial government of Vienna in 1763. The debate about the chronological priority of the two academies has been going on for a long time among the historians, but it is clearly recognized that Freiberg and Schemnitz were the first two mining academies to be set up in Europe.

Initially they had regular three- and four year courses, registered students (in Freiberg, those on grants were only Saxon, while the others paid for themselves), and employed professors, a curriculum including metallurgical chemistry, mathematics, mineralogy, and mining techniques. The Bergakademie of Freiberg could not be compared to a large university because it always maintained a provincial size. However, in spite of this, Freiberg soon became a true international mining academy that attracted students from all over Europe and America, in particular from 1775 to 1817, when Abraham Gottlob Werner [1749-1817] was professor of mineralogy, of practical courses in mining, and then of geognosy (the latter from 1778). Meanwhile other academies like Schemnitz were instead attended more by the people living in their geographical and linguistic areas of

[1415] W.A. Smeaton., "The early history of laboratory instruction in chemistry at the Ecole Polytechinique, Paris, and elsewhere," *Annals of Science*, **10** (1954), p. 224-233.

[1416] G. Lockemann and R.E. Oesper., "Friedrich Stromeyer and the history of chemical laboratory instruction," *Journal of Chemical Education*, **30** (1953), p. 202-204.

[1417] Further historical information may be found in: Donata Brianta., "Education and training in the mining industry, 1750-1860: European models and the Italian case," *Annals of Science*, **57** (2000), no. 3, p. 267-300. • Martin Guntau., "Geologische Institutionen and Staatliche initiativen in der Geschichte," (pp. 229-239) in: M. Büttner and E. Kohler, eds., *Geosciences/ Geowissenschaften. Proceedings of the Symposium of the XVIIIth International Congress of History of Science*. III. Teil. 1991. • Leopold O. Knobloch., *Bergstudenten: Geschichte und Brauchtum an den Montanhochschulen in Schemnitz, Clausthal, Freiberg und Leoben*. Mit Beiträgen von Leopold O. Knobloch, et al. Köln, SH-Verlag, 2003. 99 p., illus. [History of mining academies.; Published as *Kleine Schriften der GDS*, Nr. 16.; ISBN 3894981385.]

[1418] G.A. Smirnov., "[Role of V.N. Tatistchev in the development of mining and geological prospecting in the Urals]" (pp. 132-154) in: *Ocherki po Istorii Geologicheskikh Znanii*, **5** (1956). Moscow, Akademii Nauk SSSR. [In Russian]

[1419] Arthur Birembaut., "L'enseignement de la minéralogie et des techniques minières" (pp. 365-418) in: René Taton, ed., *Enseignement et diffusion des sciences en France au XVIIIe siècle*. Paris, Hermann, 1986. • Henry Faul and Carol Faul., *It Began with a Stone: A History of Geology from the Stone Age to the Age of Plate Tectonics*. New York, John Wiley and Sons, 1983. • Walther Fischer., "400 Jahres Sachsisches oberbergamt Freiberg [1542-1942]. Die Bedeutung dieser Dienststelle für Entwicklung der Geologie und Laggerstatten," *Zeitschrift der Deutschen Geologischen Gesellschaft*, **95** [1943], no. 3/4, p. 143-83. [History of the first 400 years of mining in Freiberg.] • Martin Guntau., "Geologische Institutionen and Staatliche initiativen in der Geschichte," (pp. 229-239) in: M. Büttner and E. Kohler, eds., *Geosciences/ Geowissenschaften. Proceedings of the Symposium of the XVIIIth International Congress of History of Science*. III. Teil. 1991. • Eberhardt Wächtler, Otfried Wagenbreth, Hans Baumgärtel, et al., *Bergakademie Freiberg, Festschrift zu ihrer Zweihundertjahrfeier*. Vol. 1. Geschichte der Bergakademie. Leipzig, Deutscher Verlag für Grundstoffindustrie, 1965.

influence.

The Bergakademie of Freiberg was certainly a model for other German mining academies, such as the Bergakademie of Berlin and the Bergakademie of Clausthal in Prussia, established in 1770 and 1775 respectively.[1420]

It was also a model for the Russian mining academy, founded in St. Petersburg in 1773 and directed by Michael Fedorovic Sojmonov [1730-1804]. This institution, later converted to a school for mining cadets (1804) and for mining engineers (1834), was one of the most important centers of geological research in Russia between the eighteenth and nineteenth centuries.[1421]

In 1777 a mining academy was established in the mining area of Almadén in Spain, which was renowned for its production of quicksilver. The school was to prepare competent technicians for local exploitations and also to send them to the gold and silver mines in the American colonies, which needed to be modernized so as to increase their production. This trend is confirmed by the creation in Latin America of two institutions such as the Academia y Escuela terico prâctica de Metalurgia (Academy and School of Theoretical-practical Metallurgy) in Potosi (1780) and the Real Seminario de Mineria (Royal Mining Seminar) in Mexico City (1792), where the Spanish scientist Andrés Manuel del Rio [1765-1849], a former student of Werner's in Freiberg, was professor of mineralogy. [1422]

In France the École Royale des Mines (Royal School of Mines) was established in 1783 in Paris and its first director was Balthazar-Georges Sage [1740-1824] who also taught mineralogy. After the Revolution period the courses recommenced in 1794 and the school was reorganized as a technical college, but after 1802 it was closed and two practical mining schools were instead opened, in Geislautern [Saar] and Pesey [Mt. Blanc]. In 1814, the École des Mines was reestablished in Paris. [1423]

The aim of the eighteenth-century mining academies, which were all promoted by governments, was to create a completely new type of higher education at the same level of the classical universities. Most of the historians agree in stating that toward the end of the eighteenth century the development of new techniques, together with the increasing demand for metals and the problems of exploitation, required the formation of a trained class of mining officers and experts. In the cases of Freiberg and Schemnitz the foundation of the mining academies was mainly the regulation and reinforcement of a local mining tradition that had long existed. It was also based on the traditional bureaucratic Central European control and fiscalism. But for example in the case of Paris, the establishment of the École des Mines was an attempt to create a completely new category of French mining experts independent from external influences.

Moreover, in the German-speaking world, the mining academies compensated for the lack of teaching of mineralogy and mining within the universities. Through the teaching programs of the new academies, the students were not simply instructed in the techniques and in the disciplines traditionally connected to mining, like metallurgy, but were also introduced to the scientific study of mineralogy and geology. Some of the professors were distinguished scientists, who played a significant role in the development of mineralogy and in the birth of geology as a science, particularly during the last decades of the eighteenth century.

[1420] Anon., "The Mining Academy of Freiberg: A Center of Geoscientific Teaching and Research," *Journal of Mines, Metals and Fuel*, **22** (1974), p. 223-227. • Hugo Strunz., *Von der Bergakademie zur Technischen Universität Berlin, 1770-1970.* Essen, Glückauf, 1979. • S. Valentiner, ed., *Die Preussische Bergakademie zu Clausthal 1775-1925.* Festschrift zur 150-Jahrfeier. Clausthal, Preussische Bergakademie, 1925.

[1421] Martin Guntau., "Geologische Institutionen and Staatliche initiativen in der Geschichte," (pp. 229-239) in: M. Büttner and E. Kohler, eds., *Geosciences/ Geowissenschaften. Proceedings of the Symposium of the XVIIIth International Congress of History of Science.* III. Teil. 1991.

[1422] Juan Manuel Lopez de Azcona., "La Minerva Hispana. Datos Históricos," (pp. 239-270) in: *Historia de la Geologia*, edited by Real Academia de Ciencias Exactas, Fisicas y Naturales. Madrid, Realigraf, 1990.

[1423] Arthur Birembaut., "L'enseignement de la minéralogie et des techniques minières" (pp. 365-418) in: René Taton, ed., *Enseignement et diffusion des sciences en France au XVIIIe siècle.* Paris, Hermann, 1986.

Among these were Werner, his colleague in the Bergakademie of Freiberg the mineralogist Johann Friedrich Wilhelm Charpentier [1738-1805]; the Italian Giovanni Antonio Scopoli [1723-1788], who had a chair of mineralogy in Schemnitz, and Christoph Traugott Delius [1720-1779], who taught mining techniques [Bergbaukunde] in the same academy. In the École de Mines of Paris, Sage was the first professor of mineralogy in 1783 and Elie de Beaumont [1798-1874] held the first chair of geology set up in 1835.

It may seem strange that in two European countries involved in mining for such a long time, such as England and Sweden, no mining academies were established in the late eighteenth century. But in Sweden under the Board of Mines [Bergskollegium] a teaching system linked to mining existed at least since 1678, and especially when Urban Hiärne [1641-1724] was director of the Laboratory of Chemistry of the Bergskollegium in Stockholm between 1683 and 1719.[1424] Hiärne made this laboratory both a center of mineral research and of education for assayers and mine supervisors. By 1725 the Bergskollegium was training five to fifteen students annually.[1425] The teaching of mineralogy in the mid-eighteenth century was also established within the Swedish University of Uppsala, where Johann Gottschalk Wallerius [1709-1785] and then Torbern Bergman [1735-1784] held the chair of mineralogy and chemistry, respectively, from 1750 and from 1767. Sweden probably did not feel the need of a mining academy based on the German model, because the government already controlled all the mining activities and education through the Bergskollegium.

In Great Britain, where the ownership of relatively small mines was mainly private, there was no impulse from the government for the creation of an extensive class of educated technologists, and the politics of British laissez-faire determined the absence of an official mining education until 1851. In 1829 an attempt to establish a school of mines in Cornwall failed and the main references for the English owners or managers of mines remained the continental mining academies, especially German and Hungarian, recognized as the most advanced in their technological teaching.[1426]

The Government School of Mines and of Science Applied to the Arts was established in 1851 in London and it became the Royal School of Mines ten years later. It was envisaged as being the teaching institution linked with the Museum of Practical Geology and the Geological Survey. Its aim was to help industry to cultivate Britain's natural resources, but soon this school became less concerned with mining and more like a central "science school," which formed a "circulating elite" of scientists operating from Africa to Australasia in the last quarter of the nineteenth century.[1427]

Since the end of the eighteenth century the mining academies were flanked by mining schools that were more technical-practical and that did not pretend to place themselves at the same level of the universities. Some mining schools had already been established in Hungary in 1747 and in France in 1767; they expanded during the nineteenth century.[1428] Some examples: in Germany, among the first mining schools, must be quoted the Freiberger Bergschule in Saxony and the Königliche Freie Bergschule Steben in Prussia, which were established respectively in 1777 and 1794. In France a mining school was founded in Saint Etienne [1816], but it was soon converted to a school for civil engineers. The first

[1424] Svante Lindqvist., *Technology on Trial. The Introduction of Steam Power Technology into Sweden, 1715-1736*. Uppsala, Almqvist and Wiskell International, 1984.

[1425] Theodore M. Porter., "The Promotion of Mining and the Advancement of Science: The Chemical Revolution of Mineralogy," *Annals of Science* **38** (1981), p. 543-570.

[1426] Roy Porter., "The Industrial Revolution and the Rise of the Science of Geology," (pp. 320-343) in: M. Teich and R. Young, eds., *Changing Perspective in the History of Science*. London, Heinemann, 1973.

[1427] Roy MacLeod., "Instructed Men and Mining Engineers: The Associates of the Royal School of Mines and British Imperial Mining, 1851-1920," *Minerva: Review of Science, Learning, and Policy*, **32** (1994), p. 422-439. • James A. Secord., "The Geological Survey of Great Britain as a Research School, 1839-1855," *History of Science*, **24** (1986), p. 223-275.

[1428] Arthur Birembaut., "L'enseignement de la minéralogie et des techniques minières" (pp. 365-418) in: René Taton, ed., *Enseignement et diffusion des sciences en France au XVIIIe siècle*. Paris, Hermann, 1986.

Italian mining schools were established by the government after the unification of Italy, in Caltanissetta [1862], Agordo [1867], Massa [1871], Iglesias [1871], and Massa Marittima [1919].[1429]

The Colorado School of Mines, the most distinguished in the United States, was established in 1870,[1430] while in Poland a School of Mining and Boring was founded in Boryslaw in 1896, followed by the Academy of Mining and Metallurgy of Krakow in 1919.

To date the mining academies have been studied only individually within local contexts and a historical general synthesis concerning their activities does not yet exist. A general discussion is needed especially for the eighteenth century, which was the crucial time of their formation and development. The importance of the mining academies for the development of the sciences of the Earth is certainly accepted by historiography, but it definitively needs more support from new researches in depth on primary sources.

Banská Štiavnica [Hungarian: Selmecbánya, German: Schemnitz] is a town in central Slovakia, in the middle of an immense caldera created by the collapse of an ancient volcano. The town was a foremost center of innovation in mining industry. In 1627, gun powder was used here for the first time in the world in a mine. In 1735, the first mining school in the country was founded there by Samuel Mikovíny. Queen Maria Theresa transformed it into the Mining Academy in 1762, thus creating the first institution of higher technical education in the world. In 1919, after the creation of independent Czechoslovakia, the Academy was moved to Sopron in Hungary.[1431]

The first ever international scientific society had been the Societät der Berbaukunde which had been formed in 1762 in Schemnitz [Banska Stiavnica], in what was then the Austro-Hungarian Empire but is now in Slovakia, and had had as members most of the well known scientists of the day. In the light of this, the new Society, it was decided, would be called the Society of Mining Professors in English, but it would also have the German name Societät der Berbaukunde in memory of that original society.[1432]

## 13.3 Textbooks[1433]

**REWORK:** Textbooks are a specific class of literature, written specifically to give instruction in the topic under discussion. In mineralogy, textbooks ...

## 13.4 Mineralogical Societies & Clubs[1434]

[1429] Umberto Chiaramonte., "Sviluppo e scuole minerarie dopo l'Unità," [Development and Mining Schools after the Unification [of Italy]], *Ricerche Storiche*, **22** (1992), no. 1, p. 89-129.

[1430] John Adams Church., "Mining schools in the United States," *North American Review*, (January, 1871). [Mining schools and education in the United States.] • Guy T. McBride., *Wealth of Good Learning*. The Story of the Colorado School of Mines. New York, Newcomen Society in North America, 1974.

[1431] Gustav Faller, et al., *Gedenkbuch zur hundertjährigen gründung der Königl. ungarischen berg- und forst-akademie in Schemnitz 1770-1870*. Schemnitz, A. Joerges, 1871. iv, 389 p., illus., diagrams. • O. Tomecek and Ivan Herčko., *Chémia a mineralógia na Baníckej akadémii v Banskej Štiavnici*. B. Bystrica, 2001. [History of chemistry and mineralogy at the Schemitz mining academy.] • Jozef Vlachovich., "Die Bergakademie in Banska Stiavnica [Schemnitz] im 18.Jahrhundert," (pp. 206-220) in: Erik Amburger and Michal Ciesla, ed., *Wissenschaftspolitik in Mittel- und Osteuropa*. Berlin, Verlag Ulrich Camen, 1976. • L. Zsámboki, et al., *Emlékkönyv Selmecbánya 1762-2002. Gedenkbuch Schemnitz 1762-2002. Pamätník B. Štiavnica 1762-2002*. Miskolc - Košice, 2002. [A history of the mining academy at Schmeitz, from 1762 to 2002.]

[1432] G.B. Fettweis and G. Hamann, eds., *Über Ignaz von Born und die Societät der Bergbaukunde. Vorträge einer Gedenkveranstaltung zur 200. Wiederkehr des Gründungstages im September 1786 der ältesten internationalen wissenschaftlichen Gesellschaft herausgegeben von Günter B. Fettweis und Günther Hamann*. Wien, Verlag der Österreichischen Akademie der Wissenschaften, 1989. 153 p., illus., ports. [ISBN 3700116314]

[1433] Further historical information may be found in: J.A. Nietz., *The evolution of American secondary school textbooks; rhetoric & literature, algebra, geometry, natural history (zoology), botany, natural philosophy (physics), chemistry, Latin and Greek, French, German & world history as taught in American Latin prior to 1860*. Rutland, Vermont, C. E. Tuttle Co., 1966. [i]-xii, [1]-265 p., facsims., portraits., index.

[1434] Further historical information may be found in: H.C. Dake., *Mineral club history*. Portland, Oregon, Durham, Ryan & Downey Co., 1943. 64 p., portraits. [Describes the history of various U.S. mineral clubs.] • E. Sparn. "Cronologia, diferenciacion, matricula y distribucion geografica de las sociedas de mineralogia, geologia, y palentologia," *Boletín de la Academia Nacional de Ciencias en Córdoba*, **36** (1942), p. 1-24. [A statistical review of the general and specialized geological societies of the world, providing the dates of founding, and other data, including the size of membership.]

**REWORK:** Beginning in the sixteenth century, numerous learned and scientific societies were founded, including the famous Royal Society of London ( founded in 1662). Although mineralogy was commonly among rhe interests of these organizations, the scope of their activities generally spanned a broad spectrum of the sciences. It was not until the conclusion of the eighteenth century that societies devoted specifically to mineralogy and the earth sciences arose.

1797 Jena, Germany. *Societät für die gesammte Mineralogie zu Jena.*

1799 *British Mineralogical Society.*

1799 *American Mineralogical Society.*

1807 *Geological Society of London.*

The Mineralogical Society of Jena.[1435]

### North America

Mineralogical Society of America ....[1436]

Geological Society of America ...[1437]

Mineralogical Society of America ...[1438]

New York Geological Survey ....[1439]

In the United States the oldest club is the Philadelphia Mineralogical Club which still exists ...[1440]

### Europe

Societe Geologique de France ...[1441]

Società Geologica Italiana ....[1442]

Società Geologica Italiana ...[1443]

Finska Vetenskaps-Societeten ... [1444]

Vereins für vaterländische Naturkunde in Württemberg ...[1445]

Geological Society of London ...[1446]

### Africa

Geological Society of South Africa ....[1447]

## 13.5 Journals & Periodicals[1448]

**REWORK:** The end of the eighteenth century marked the founding of journals and periodicals devoted specifically to mineral studies, often (but not always) in connection with the early mineralogical societies. Before that time, the mineralogist published their articles in more generalized scientific oracles, such as the *Philosophical Transactions of the Royal Society in London*, the *Mémoires of the Royal Academy of Science* in Paris, and the *Annales*

[1435] G. Csiky., "The role of Hungarian naturalists in the establishment and operation of the 'Mineralogische Söciete' in Jena, including its influence on the development of the earth sciences in Hungary" (pp. 423-40), in: Vitális and Kecskeméki, eds., *Museums and Collections in the History of Mineralogy, Geology and Paleontology in Hungary*. Budapest, 1991. • J. Salomon., *Die Sozietät für die gesamte Mineralogie zu Jena unter Goethe und Johann Georg Lenz*. Köln & Vienna, Böhlau Verlag, 1990. 232 p., biblio., index. [History of the first mineralogical society, founded at Jena, Germany.]

[1436] George Phair., "The founding of the Mineralogical Society of America," *American Mineralogist*, **54** (1969), nos. 9-10, 1244-55.

[1437] Herman LeRoy Fairchild., "Review of the early history of the Society," *Geological Society of America*, Bulletin, **24** (1914), p. 133-162.

[1438] D. Jerome Fischer., "Mineralogical Society of America — the history of MSA, an AGI member society," *Geotimes*, **7** (1963), no. 6, p. 8-12, illus.

[1439] James Hall., "The New York Geological Survey," *Popular Science Monthly*, **22** (1883), p. 815-825.

[1440] Minutes of the club meetings were published in the *Mineral Collector* during its run from 1894 to 1909.

[1441] *Centenaire de la Societe Geologique de France. Livre Jubilaire. 1830-1930.* Paris, 1930. 2 vols. [1]-328 p.; 331-660 p., portrait, 54 plates and maps. [Centenary history of the Geological Society of France.].

[1442] Enrico Clerici., "La Società Geologica Italiana nel suo primo cinquantennio di vida," *Soc. Geol. Italiana*, Memoires, **1** (1933), p. 7-18. [History of the Geological Society of Italy during its first 50 years.]

[1443] *Cento Anni di Geologia Italiana.* Volume Giubilare: 10 Centenario della Società Geologica Italiana, 1881-1981. Roma, La Società, 1984. 443 p., illus., maps. [History of the first one hundred years of the Società Geologica Italiana.]

[1444] Adolf E. Arppe., "Krystallografi, Mineralogi, Geologi" (pp. 69-89) in: *Finska Vetenskaps-Societeten 1838-1888, dess organisation och verkasamhet*. Helsinki, J. Simelii Arfu, 1888. 159 p.

[1445] M. Rauther., "100 Jahre Verein für vaterländische Naturkunde in Württemberg," *Jahreshefte des Vereins für vaterländische Naturkunde in Württemberg*, Jg. 97-101 (1949), p. vii-xxii. [History of the society from 1844 to 1944.]

[1446] Horace B. Woodward., *The history of the Geological Society of London.* London, Geological Society, 1907. [i]-xx, [1]-336 p., 13 plates, index.

[1447] Harold S. Harger., "The early history of the Geological Society of South Africa," *Transactions of the Geological Society of South Africa*, **48** (1946), p. i-x, 3 plates (portraits). [The society was founded in 1895.]

[1448] Further historical information may be found in: H.C. Bolton., *A catalogue of scientific and technical periodicals, 1665-1895. Together with chronological tables and a library check-list.* Second edition. Washington, Published by the Smithsonian Institution, 1897. [4], vii, [1], 1247 p., indexes. • Marco Beretta, et al., ed., *Journals and history of science.* Firenze, L.S. Olschki, 1998. vii, 268 p, illus. • Meyer, *History of Chemistry*, 1898, p. 594-598.

*de Chimie et de Physique* in Paris. But by the close of the eighteenth century division of the sciences was becoming very pronounced, and magazines sprang up devoted to specific studies, including minerals.

One of the first attempts at serial devoted to mineralogy was the *Magazin für die Mineralogie und mineralogische Technologie*, published in Halle by Johann Hermann Pfingsten [1751-1798]. Only two issues appeared, published in 1789 and 1790.

Karl Ernst Adolf von Hoff [1771-1837], director of the Ober-Consistorium in Gotha, and an enthusiastic mineral collector, brought out the *Magazin für die gesammte Mineralogie, Geognosie und mineralogische Erdbeschreibung*, which was published in Leipzig in 1801. It was short lived, lasting only four issues.

Johann G. Lenz published the annals and journal of the Mineralogical Society of Jena (*Annalen der Societate für die gesammte Mineralogie zu Jena*; *Schriften der Herzoglichen Societät für die gesammte Mineralogie zu Jena*) beginning in 1802 and ending after six volumes in 1825.

The noted German mineralogist, Karl Ceasar von Leonhard [1779-1862] published his *Taschenbuch für die gesammte Mineralogie* (known popularly as "Leonhard's Taschenbuch") from 1807 to 1824. The articles included travel reports from corresponding mineral collectors, summaries of recent mineral analyses, reports on mineral localities, reviews and descriptions of important public and private mineral collections, death notices of mineral people, and even advertisements regarding mineral specimens and collections for sale. Subsequently, Leonhard's journal was continued through a series of mineralogical journals, with the present day title being the *Neues Jahrbuch für Mineralogie*.

In America, Archibald Bruce founded the *American Mineralogical Journal*, which began in 1810. Although it ended after only four years, due to Bruce's untimely death, the concept was continued on in 1818 by Benjamin Silliman, who broadened its scope, and named it the *The American Journal of Science, more especially of Mineralogy, Geology, and the Other Branches of Natural History*. "Silliman's Journal," as it was popularly known in the nineteenth century, continues to be published as a general-science journal.

This is not to say that more general periodicals did not also continue to publish mineralogical news and research. *Nicholson's Journal*, the *Edinburgh Philosophical Journal*, the *Edinburgh Journal of Science*, the *Annales du Muséum d'Histoire Naturelle* in Paris, *Gehlen's Journal für die Chemie und Physik*, and the *Abhandlungen der Königlichen Akademie der Wissenschafen* in Berlin all carried mineralogy. But the more specialized mineralogical journals were now leading the way, supported by a broad spectrum of collector and academics. Thanks in part to the enthusiasm and support of the amateur community of mineral collectors, the periodical literature of mineralogy had clearly become well-established at last.

The journals that focused on mineralogy include the following titles:

Johann Lempe's *Magazin für die Bergbaukunde* (Dresden, 1785-1799).

Alexander Köhler's *Bergmännisches Journal* (Freiberg, 1788-1793).

*Neues Bergmännisches Journal* (Freiberg, 1795-1804).

*Annales de chimie et de Physique* (Paris, founded by Lavoisier, Dietrich, Fourcroy and others in 1789).

Friedrich Gren's *Journal de Physik* (Halle, Dresden and Leipzig, 1790-1800).

*Journal des Mines* (Paris, founded by Haüy, Vauquelin, Brochant and others in 1794).

Johann Denso's *Monatliche Beiträge zur Naturkunde* (Berlin, 1752-1765).

Johann Schröter 's *Journal für die Liebhaber des Steinreichs und der Konchyliologie* (Weimar, 1774-1780).

Lorenz von Crell's *Chemical Journal, Archiv and Annale* (Lemgo, Leipzig, and Weimar, 1778-1779).

Ludwig Lichtenberg *Magazin für den Neuesten aus der Physik und Naturgeschichte* (1781-1799).

Johann Voigt's *Magazin für den neuesten Zustand der Naturkunde* (Jena and Weimar,

1797-1806).

*The Philosophical Magazine* (founded 1789, London).

*Philosophical Transactions of the Royal Society* (London, 1666).

*Mémoires de la Académie Royale des Sciences* (Paris, 1667).

*Mineralogist's Monthly.*

*The Mineral Collector.*

*The Exchanger's Monthly.*

*The American Mineralogist.*

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George Phair., "The American Mineralogist — its first four years," *American Mineralogist*, **54** (1969), nos. 9-10, p. 1233-1243.

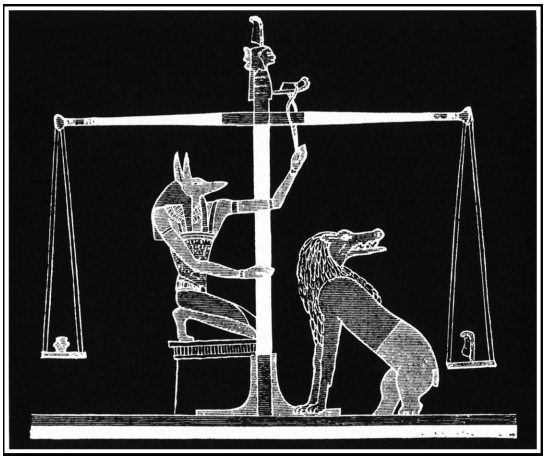
## 14.0 Instrumentation[1449]

The instruments devised by mineralogists in determining the physical, crystallographic, and chemical properties of minerals show a wide range of varieties. Experience has shown that in experimental work the introduction of a new tool enables the researcher to explore fields previously inaccessible because of the lack of the proper weapons of attack. But the introduction of a new method or a new instrument may enable the observer to explore new fields heretofore inaccessible.

1913: Berek M. (1913a) Mineralogisches Demonstrationsapparat. Centralblatt Mineral. 1913, 181-189.

## 14.1 Analytical Balances[1450]

**REWORK:** Among the first instruments to make accurate measurements was the analytical balance. The art and science of weighing was known in Egypt as early as 3000 B.C.E. The earliest written reference to an equal arm balance dates back to approximately 1300 B.C.E., as described in the papyrus of Hannafer. Also a reference to weights and balance is made in Proverbs 11:1: "A false balance is an abomination to the Lord, but a just weight is his delight."



Egyptian Equal Arm Balance (c1300 B.C.E.)

Representations of balances are known from Egyptian papyri, in which hearts of the dead are weighed against truth. The mode of suspension of the beam is not clear, but pans are hung from the beam ends and weights may be moved along the beam to attain their balance. An example of such an illustration is found on a British Museum copy of the Book of the Dead dating from ca. 1320-1290 B.C.

[1449] Further historical information may be found in: Trevor Harvey Levere and Frederic Lawrence Holmes., *Instruments and Experimentation in the History of Chemistry*. Cambridge, MIT Press, 2000. 415 p. [ISBN 0262082829.] • F.E. Wright., "Methods and instruments used in mineralogy," *American Mineralogist*, **27** (1942), p. 145-154.

[1450] Further historical information may be found in: A. Barclay., "Early technical balances," *Sands, Clays & Minerals*, **3** (1938), no. 3, p. ??-??. • Ernest Child., *The tools of the chemist. Their ancestry and American evolution.* New York, Reinhold Publishing Corporation, 1940. 220 p., index, 106 illus. [A history of chemical apparatus, describing the inventors and inventions. Copiously illustrated with portraits and drawings of the equipment.] • Ihde, *History of Chemistry*, 1964, p. 283-284. • Jenemann, Hans R. Die Waage des Chemikers. Frankfurt am Main: Dechema, 1979. • *ibid.*, "Zur Geschichte der Waage in der Wissenschaft." In Beitrage zur Geschichte der Laboratoriumstechnik und deren Randgebiete, edited by E.H.W. Giebeler and K.A. Rosenbauer, 97-119. Darmstadt, G-I-T Verlag Ernst Giebeler, 1982. • Laitinen, *History of Analyitical Chemistry*, 1977, p. 8-10, 33-34, and 49-52. • Robert P. Multhauf., "On the use of the balance in chemistry," *Proceedings of the American Philosophical Society*, **106** (1962), p. 210-8, illus. [In this paper he focuses mainly on the introduction of the balance in experimental chemistry, the pneumatic chemists, and Lavoisier.] • Partington, *History of Chemistry*, 1961-70. [Scattered notes through out the four volumes.] • John M. Shannon and Geraldine C. Shannon., *The assay balance. Its evolution and the histories of the companies that made them.* Englewood, Colorado, [The Authors], 1999. 241, [1] p., illus. [ISBN 0-9676841-1-0.] • Stock, John T. Development of the Chemical Balance. London: Her Majesty's Stationery Office, 1969. • Szabadváry, *History of Analytical Chemistry*, 1966, p. ??-??.

Roman balance beams and steelyards survive in some numbers, and there can be no doubt that weighing was a common procedure in the ancient world (see balance, general).

It was not until the Middle Ages, however, that the balance was probably used by assayers, when one of the early applications was in cupellation, which was a statutory procedure for examining gold in the 14th century. Philip VI of France described the procedure, which is perhaps one of the earliest examples of a standard method of analysis, stating that "the balance used for the test should be of good construction, precise, and should not pull to either side. The test should be carried out in a place where there is neither wind nor cold, and whoever carries out the test must take care not to burden the balance by breathing upon it."



Mediaeval Alchemist with Balance (c1400)

The earliest balances developed for a chemical purpose are probably those used in assaying processes, for which small globules of gold need to be weighed. A manuscript of Thomas Norton's Ordinall of Alchimy of the late fifteenth century contains an illumination of a laboratory in which distillation processes are occurring. On a sturdy table stands a balance in what appears to be a glazed case.

The development of assay, pharmaceutical, and coin balances appears to have remained independent of improvements to increase the sensitivity of chemical balances: the former continued to be conservative in design. For example they retained the solid, rodlike beam and swan-neck ends long after the latter had abandoned them for more rigid beams and more precise suspension systems.

It could be argued that chemical balances developed from hydrostatic balances of the early eighteenth century. These were used to determine the specific gravity of liquids by determining the weight of a metal mass immersed in water and then in the liquid to be determined. These balances were described by John Harris in his *Lexicon Technicum* of 1710 and at least two examples survive, one in the Royal Museum of Scotland having been used by Andrew Plummer, the professor of chemistry at Edinburgh University, in his work on the spa water of Moffat in the south of Scotland.

The earliest surviving balance used for a published series of chemical experiments is said to be that used by Plummer's successor at Edinburgh, Joseph Black, who described work on the alkaline nature of magnesia alba (basic magnesium carbonate) in his doctoral thesis of 1754. This was an important experiment because it led to the discovery of fixed air (carbon dioxide), the first gas to be chemically identified. The balance is crudely made with a simple suspension of the beam on a knife edge. The beam has swan-neck ends from which the pans are hung directly by cords. Tests have shown that the balance is sensitive enough to have provided the results recorded by Black, even though Lyon Playfair referred to it in 1876 as "a grocer sort of balance ... no better than a grocer's scales."

Though chemists demanded higher levels of sensitivity, balance makers tended to be conservative. Even though Antoine Laurent Lavoisier's balances were constructed to the highest level of craftsmanship by Nicolas Fortin and Pierre Bernard Megnie, they show few innovations. Significant improvements were to be introduced by work directed through

the Royal Society and commissioned by the British government, which needed accurate measurements of the specific gravity of water-alcohol mixtures in order to exact taxes in a scientific manner. A brilliant instrument-maker, Jesse Ramsden, was given the task, and he realized that the inaccuracies of existing balances were caused by the flexing of beams when they were loaded. This he tackled by creating a much more rigid beam from two hollow brass cones joined at their bases. They carried a central steel knife that turned on an agate plane. Pan hangers used a suspension known as "slide and knives." These two features reduced the variation in the exact point of suspension present in earlier balances. Ramsden's balance provided the accuracy required, but the long, massive beam swung very slowly and each measurement took a very great time to take.

Analytical balances before the first quarter of the 19th century were custom made by craftsmen who specialized in the construction of scientific instruments. The first balances of standardized design were made by a London instrument maker named Robinson shortly before 1825. In the United States such balances were first manufactured and sold about 1855 by Christopher Becker, a Dutch instrument maker who had settled in New York city.

The analytical balance in use in the first half of the 19th century had a long solid, hollow, or open-work, brass or bronze beam with a central knife edge of steel or agate resting on a polished flat piece of the same material placed on the top of a supporting pillar. A pointer attached to the center of the beam moved over a graduated scale placed low on the pillar. The pans were suspended by thin metal wires or silk threads from hooks at the ends of the beam. The beam was controlled by a simple arresting mechanism, but there were no pan arrests. None of these early balances was very sensitive, about 0.5 mg at best. With such balances weighing was tedious, not only because of the slow movement of the long beam and lack of pan arrests but because all weights, even the smallest, had to be added and removed from the weight pan by forceps.

The problem of the need for lightness and rigidity in balance beams was successfully tackled by a London manufacturer, Thomas Charles Robinson, who has been described as the first manufacturer of precision balances. Around 1820 he supplied the chemist William Hyde Wollaston with a short beam balance, the beam being of a perforated triangular design. Adjustments could be made to each end of the beam and there was a short vertical pointer that moved over a scale to determine the null point. This beam design was soon widely adopted, and analytical chemists could order similar instruments from precision makers: Andrew Ure from F.W. Breithaupt in Kassel, Germany, and Jons Jacob Berzelius from C.E. Littman of Stockholm, for example. The Berlin maker Ludwig Oertling settled in London in the early 1850s and for the rest of the century—and beyond—his firm was the leading manufacturer in Britain.

The improvements made in balances in the second half of the century were mostly directed to increasing sensitivity and reducing the time required for weighing. The graduated beam with rider was introduced shortly after 1850 by L. Oertling.

In Germany, Paul Bunge of Hamburg built short-beam analytical balances from 1866 that had highly engineered knives and planes. Florenz Sartonus, who founded his firm in Gottingen in 1870, was the first to use aluminum in beam construction.

Becker's balances of the third quarter of the 19th century, though still of the long-beam type, had pan arrests and agate knife edges for supporting the pans. Paul Bunge of Hamburg, Germany, constructed the first rapid, short beam balance in 1866. In the last quarter of the century the Sartorius company of Gottingen, Germany, began to manufacture balances with short, triangular, aluminum beams and with a synchronized system of beam and pan arrests. Although the chain weight device was invented as early as 1890, the first successful Chainomatic balance was not developed until 1915 when Christopher A. Becker received a patent for a balance of this type.

Microanalytical balances were developed at the end of the 19th century. E. Warburg and

T. Ihmori described in 1886 a microbalance; this development was followed by E. Salvioni with a spring balance around 1900 and the first quartz fiber balance by Walther Nernst in 1903. Nernst and E. H. Riesenfeld used this type balance for atomic weight determination of rare earths shortly thereafter. Modified Nernst balances served F. Emich and J. Donau for the weighing of precipitates in milligram amounts. Emich also had ordered from the balance manufacturer, Wilhelm H. F. Kuhlmann in Hambura, a special assay balance with a sensitivity of 1x10 g and a load capacity of 20 g, which he used sometimes when the load overstepped the capacity of the Nernst-type balances. F. Pregl used an improved Kuhlmann balance with a reproducible sensitivity of 1 x 10 and a load capacity of 20-30 g in his development of quantitative organic microanalysis. These balances came to be known as microchemical balances of the Kuhlmann type.

F. Emich constructed still more sensitive weighing instruments (described in 1915 and 1921) ; one had a solid quartz beam, a quartz fiber suspension, and weight compensation by electromagnetic power, reaching a reproducible sensitivity of 5 x 10 9 g.

Precision balances of the suspension type, as well as weighing instruments based on other principles, have been described on several occasions by F. Emich in 1915, by Georg Gorbach in 1938, and in numerous publications by A. A. Benedetti-Pichler. An important advance in balance construction was made by Erhard Mettler in 1945 by deviating from the equal arm construction and introducing the substitution principle.

## 14.2 Blowpipes[1451]

**REWORK:** The mineralogist of today is often unaware of the importance of that most simple instrument, the blow-pipe. The common blow-pipe is not, today, an tool that excites the interests of aspiring chemists and mineralogists, and, although it may still be used from time to time in the field, it is generally to be found in scientific insturment collections, regulated to an historical curiosity. By contrast, in the eighteenth and nineteenth centuries, it was an important insturmentfor chemists, mineralogists, and metallurgists, with numerous papers and books describing the uses of this deceptively simple apparatus.

It was directly as a result of this device that the first qualitative determination of many mineral substances was made, and it was directly from the use of the blow-pipe that several elements were recognized for the first time.



Egyptian Blowpipe Artistian (c1500 B.C.E.)

That the blow-pipe had been used in antiquity is known from depictions of it in use preserved in the tomb paintings of Beni Hasan.[1452] Apparently metal workers used it

[1451] Further historical information may be found in: Ulrich Burchard., "The history and apparatus of blowpipe analysis," *Mineralogical Record*, **25** (1994), p. 251-277. • Sidney M. Edelstein., "An historic kit for blowpipe analysis," *Journal of Chemical Education*, **26** (1949), p. 126-131. • William B. Jensen., "The development of blowpipe analysis" (pp. 123-149) in: J.T. Stock and M.V. Orna, eds., *The History and Preservation of Chemical Instrumentation*. New York, D. Reidel Pub. Co., 1986. • H.R. Lee., "Mineralogy and the blowpipe art," *Rocks and Minerals*, **13** (1938), no. 8, p. 227-235. • Orsino C. Smith., "Chap. 2, The blowpipe and its uses, history of blowpiping" (pp. 29-31) in: Orsino C. Smith., *Identification and Qualitative Chemical Analysis of Minerals*. New York, 1953. • Thomas Thomson., [History of blowpipes] (**2**, pp. 240-246) in: T. Thomson, *History of Chemistry*. London, 1831. • C.E. Weigel., "Versuch einer Geschichte des Blaserohrs und seine Anwendungen," *Beiträge zu den Chemischen Annalen* (Crell's *Beiträge*), **4** (1790), p. 262-283, 393-419; **6** (1794), p. 6-24, 198-216. [Very early history of the blowpipe.]

[1452] Beni Hasan (12th Dynasty, c2000-1800 B.C.), see: P.E. Newberry, Beni Hasan. (Published under the auspices of the Eygtian Exploration Fund), Part I, London, 1893, plate XI; and Part II, London, 1894, plates IV and VII. Citation from Oldroyd (1972), p. 220.

to provide a jet of air into the fire used to melt the various metals. The technology appears to have vanished until the Renaissance, however.

During the seventeenth century, the blow-pipe is found to be widely used in the glass industry.[1453] The Journal of the Academia del Cimento in Florence for the year 1660 describes a small pipe with which glass blowers using their mouths like bellows were able to create very delicate glass-work.[1454] Johann Kunckel also describes this instrument in his famous treatise about the glass industry, Ars vitraria experimentalis oder vollkommene Glasmacherkunst. Of particular interest is the passage Kunckel uses to end his discussion of the blow-pipe.

"Also many possibilities are concealed in this art; in a chemist's workshop, for example, it might prove to be very useful. For example, one use would be to melt a metal-lime in order to see what metal it contains; there are many other possible uses. It is necessary only to place the lime to be analyzed into a hollow in a small piece of charcoal and to blow the flame on to it for a very short time." [1455]

Kunckel's suggestion was taken up by Stahl[1456] who reports using a tublulo cæmentario aurifabrorum[1457] in connection with an analysis of antimony and lead-lime (oxide) on a block of coal.[1458] But Johann Cramer appears to be the first to use the technique extensively. Employing a charcoal block in which a sample was placed in a small depression, Cramer used the directed flame of the blowpipe to melt the sample. He appears also to be the first to record the reaction of various minerals when melted with a small amount of borax.[1459]

Cramer's blow-pipe was made of copper, and included a small ball-like opening to collect the condensation from the breath during blowing (see figure ). This was an important innovation in the design, as it allowed the blow-pipe to be used for very extended periods, without the condensation clogging the flow of air through the tube.

Marggraf in his examination of phosphorous and phosphoric acid made reference to the use of the blow-pipe. He reports that the precipitate formed when phosphoric is added to gold when heated in the flame of a blow-pipe easily fuses to an opaque glass, and silver phosphate he describes as yielding a dark glass in the heat of a blow-pipe. Maggraf does not describe how to use of the blow-pipe, inferring it to be known well enough not to need explanation.

Another early researcher who used the blow-pipe with efficiency was Johann Heinrich Pott. In his search for the secrets of manufacturing Meissen porcelain, Pott conducted many thousands of experiments. The published record of his observations include every known analytical technique of the period. Thus buried among the meticulous observations are many references to reactions before the blow-pipe flame. These included

[1453] Weigel, C.E., "Versuch einer Geschichte des Blaserohrs und seine Andwendungen," Beyträge zu dem chemischen Annalen (Crell's Beyträge), 4 (1790), 262-283, 393-419; 6 (1794), 6-24, 198-216, gives a very detailed account of the blow-pipe's history in the glass industry, particularly with reference to making thermometers. Weigel though is not able to trace the instrument back to its first application. As he concludes, when an artisan develops a tool of this type, it may be many years, before any mention of it is recorded in the literature.

[1454] Weigel, C.E., "Versuch einer Geschichte des Blaserohrs und seine Andwendungen," Beyträge zu dem chemischen Annalen (Crell's Beyträge), 4 (1790), 262-283, 393-419; 6 (1794), 6-24, 198-216, gives a very detailed account of the blow-pipe's history in the glass industry, particularly with reference to making thermometers. Weigel though is not able to trace the instrument back to its first application. As he concludes, when an artisan develops a tool of this type, it may be many years, before any mention of it is recorded in the literature.

[1455] Knuckel, J. Ars vitraria experimentalis oder vollkommene Glasmacher Kunst. Frankfurt &Leipzig, 1689, p. 399-400. Citation and translation from Szabadvßry, F., History of Analytical Chemistry, Oxford, 1966, p. 51. Henceforth cited as Szabadvßry (1966).

[1456] George Ernst Stahl (born: 21 October 1660 at Anspach, Germany; died: 14 May 1734 at Berlin, Germany) Stahl received his M.D. from University at Jena in 1683. He was a professor of medicine at the University at Halle from 1694 to 1716, afterwhich he was appointed chief physician at the royal Leopoldin Academie in Berlin.

[1457] Kunckel added the German description of Lothröhrichen, which has the derived meaning: löthen, to solder, and rohr, a tube or pipe.

[1458] Stahl, G.E. , Specimen Becherianum, cited in: Kopp, H., Geschichte der Chemie, 4, p. 413.

[1459] Cramer, J., Elements of the Art of Assaying Metals ... Translated from the Latin ..., London, 1741. The Latin edition which I have not seen was published at Leyden in 1739.

notice of melting point, color, appearance after melting, etc., for many minerals, much of which had not previously been recorded. These references to the blow-pipe were for the most part isolated occurances. It would not be until the mid-eighteenth century that the insturment came into widespread use.

The increased popularity of the blow-pipe was a direct influence of the Swedish metallurgists and mining authorities. According to Bergman, Anton von Swab in 1738 was the first to use the tool in a analysis of antimony, but publication of the paper was delayed for a decade. Prior to the appearance of Swab's article then we find Sven Rinman's report of the examination of iron contaminated tin ores that was based upon blow-pipe examination. He also used the blow-pipe in developing the Rinman-green zinc test.

The widespread use of the blow-pipe in analyses during the later half of the eighteenth century can be traced to another Swede, Axel Frederic Cronstedt. He first mentions results obtained from blow-pipe examination in his historically important papers describing the discovery of the new element, nickel. But it is in his important mineralogical work Försok till mineralogiens eller Mineral-Rikets upsällning first published in 1758, that blow-pipe analysis generally became recognized as a viable and important technique. Using results obtained from this simple instrument, Cronstedt reformed the traditional divisions of earths and stones in mineralogy by creating nine new classes, each of which could be determined directly by blow-pipe analysis. Swedish mineralogists were the first to recognize the merit of Cronstedt's theories, and many made the pilgrimage to work with the master and learn his techniques directly. For Cronstedt, himself, never described the blow-pipe technique in any of his works. This was left for Engström to add as an appendix when he prepared an English translation of Cronstedt's book. It was this appendix that promoted the value of blow-pipe analysis during the last decades of the eighteenth century. Engström's description became so popular in fact, that it was separately translated into several languages including Swedish.

Bergman probably the greatest analyst of the eighteenth century was next to describe the importance of the blow-pipe. He first made reference to its use in his first chemical publication - an investigation of alum. After that many other mentions of the blow-pipe appear throughout his writings. He believed the technique of enough value as to merit its own handbook. Thus in 1779 he published De tubo feruminatorio containing all existent knowledge on the use and the results obtained with the instrument. In this work he describes all the intricacies of the blow-pipe, and its many advantages over furnace methods. Namely that a blow-pipe does not require very much specialized apparatus, very little sample is required, and the operation is very rapid. Bergman further points out that a quantitative estimation of composition is not possible with a blow-pipe This is one of the earliest indications of recognition between the difference of quantitative and qualitative analysis. To illustrate the use of the blow-pipe, Bergman included a plate (see figure: ). He describes the method of obtaining a suitable flame, i.e., a candle or a burner fed with vegetable oil, and also suitable fusing agents, such as sodium ammonium phosphate, sodium carbonate and borax. Finally he systematically records the reactions of various mineral groups under the blow-pipe flame. Besides charcoal Bergman also used silver and gold plates on which to fuse the samples.

The technique of blow-pipe analysis was further refined by Bergman's assistant Gahn. Gahn introduced the use of a platinum wire to hold the sample, and discovered the cobalt-pearl-test. Gahn's blow-pipe design was also to remain the default standard through the years (see figure: ). Unfortunately, Gahn never published any of his blow-pipe researches. This task was left to one of Gahn's associates during the later years of his life. Jöns Jacob Berzlius made a lasting contribution to the history of mineralogy when he published his own notes of Gahn's blow-pipe techniques.

Berzelius records that Gahn became exceptionally skillful in the use of the blow-pipe, and that no one could improve on his mineral analysis even with wet methods.

He mentions that Ekeberg, who discovered tantalum, asked Gahn to examine a sample of this metal for him. Gahn was able to detect the presence of tin, although the quantity was less than 1 per cent. Perhaps more remarkable is the fact that Gahn was able to detect the presence of copper in the residue of a quarter sheet of filter-paper, although it had not previously been thought that copper was a constituent of vegetable substances.

As the use of the blow-pipe became more acceptable, the instrument took on new dimensions to suit different situations in mineralogy and chemistry. On one hand portable chemical and mineralogical laboratories began to appear. These contained many items used in field blow-pipe analysis. In another direction blow-pipes began to be described in elaborate terms when restricted for use in the laboratory. Therefore, the history of this device which started so simply now travels upon two separate paths.

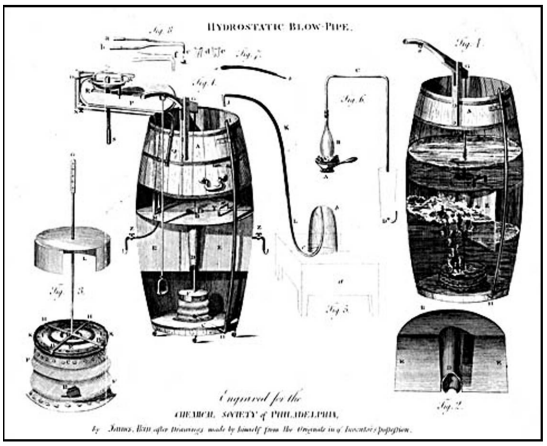
### 14.2.1 Portable Laboratories[1460]

**REWORK:** William Hyde Wollaston, an individual of considerable intelligence, was the major source of refined platinum in the early nineteenth century. Through his retailer, William Cary, tens of thousands of ounces of the metal was sold. Some of the platinum was used to manufacture items of chemical interest, including crucibles, wire, weights, scale bottoms, evaporators, tubes and blow-pipes. Because of its extremely high melting temperature and its resistance to corrosion, platinum was an ideal substance for the manufacture of chemical apparatus. Blow-pipes of platinum were made by Troughton, who made his platinum purchases from Cary. Accum must also have made platinum purchases from Cary because he included foil and "forceps entirely made of platina" with his portable mineralogical laboratory. The use of platinum foil as a support in blow-pipe analysis was not Accum's advance, but is credited to Wollaston, described as the "most skillful mineralogist of his day."

Wollaston's blowpipe...[1461]

### 14.2.2 Laboratory Blowpipes[1462]

**REWORK:** It is to the laboratory equipment that the next major advance is made in blow-pipe design. The discovery of Oxygen was credited to Priestley in 1774 AD, would greatly influence the capabilities of the blow-pipe. Achard is credited with being the inventor of the oxygen hydrogen blow-pipe, although it appears Lavoisier had a similar idea. These devices were capable of producing much higher temperatures than any other blow-pipe even with a bellows attached could possibly achieve. This led to breakthroughs in high temperature research.




Hare's Hydrostatic Blowpipe (1802)

Before he turned 20, Hare had begun to experiment toward a method of generating higher temperatures than possible in contemporary furnaces, adapting a keg from his father's brewery to develop an instrument he called the hydrostatic blow-pipe - the oxyhydrogen blow-torch. This was an instrument in which oxygen and hydrogen, taken from separate reservoirs, in the proportions of two volumes of hydrogen

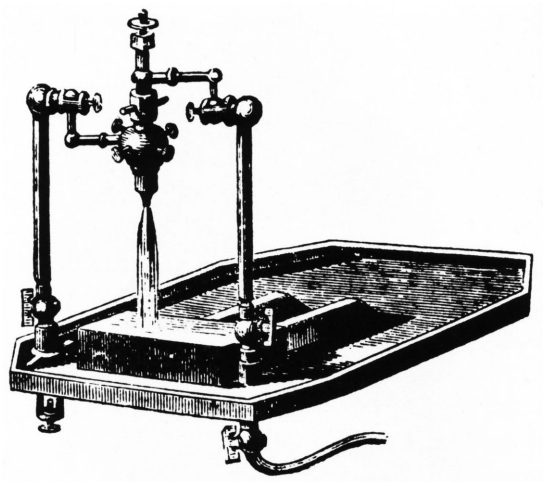
[1460] Further historical information may be found in: William A. Smeaton., "The portable chemical laboratories of Guyton de Morveau, Cronstedt and Göttling," *Ambix*, **13** (1966), p. 84-91.

[1461] William Hyde Wollaston., "Description of a portable blow-pipe for chemical experiments," *Journal of Natural Philosophy, Chemistry and the Arts* (Nicholson), **15** (1806), p. 284*-285*.

[1462] Further historical information may be found in: David R. Oldroyd., "Edward Daniel Clarke, 1769-1822, and his rôle in the history of the blow-pipe," *Annals of Science*, **29** (1972), p. 213-235.

to one of oxygen, are burned in a jet, under pressure. It gives a heat that will consume the diamond, fuse platinum, and dissipate in vapor, or in gaseous forms, most known substances. He was able to melt sizeable quantities of planium with this blowpipe.

The small pamphlet that Hare wrote to describe his invention, "Memoir on the Supply and Application of the Blow-Pipe" (Philadelphia: Chemical Society, 1802), brought him international renown when it was republished in the prestigious English Philosophical Magazine and the French Annales de Chimie. The elder Silliman, who was engaged with him in a series of experiments with this instrument in 1802-'3, subsequently distinguished it as the "compound blow-pipe." " This apparatus," says Silliman, "was the earliest and, perhaps, the most remarkable of his original contributions to science." He read a supplementary paper giving an "Account of the Fusion of Strontivres and Volatilization of Platinum, and also a new Arrangement of Apparatus " before the American philosophical society in June, 1803. Later, it was discovered that when such a blowpipe flame acted on a block of calcium oxide, a brilliant white light resulted - limelight. His device was also the ancestor of the modern welding torches. Largely on the strength of this single invention, Hare was elected to the American Philosophical Society in 1803 and was awarded an honorary medical degree by Yale in 1806, and frown Harvard in 1816.



Hare's Compound Blowpipe (c1850)

Thomas Thomson to chemistry might be indefinitely particularized. About 1802 he invented the oxy-hydrogen blowpipe, in which he introduced the oxygen and hydrogen into one vessel; but the whole apparatus having blown up and nearly proved fatal to him, he placed the gases in separate gas-holders. At that time he made many experiments on its powers of fusion, but as Dr. Hare had invented an apparatus at the same time, and published his experiments, Dr. Thomson did no more than exhibit the apparatus in his lectures.

## 14.3 Specific Gravity Measurement

**REWORK:** The density or specific gravity of a mineral is one of the oldest mineralogical properties to be measured. The specific gravity or density of a mineral is the ratio of its weight in air to that of the same volume of water, and is commonly defined as the weight of the body divided by the weight of an equal volume of water. Every mineral has a specific gravity that is unique to it because it is a feature derived from the chemical composition of the mineral. It was recognized early on that different minerals had different specific gravitates. The objective of finding the "heft" of an object was determined by weighing the material in question in air and water, and calculating the relative difference. This procedure worked well for relatively large samples, but had little value for powders or other small samples. Therefore, other ingenious methods and techniques were developed for discovering the specific gravity of tiny mineral particles.

### 14.3.1 Hydrostatic Balances[1463]

**REWORK:** Measurements of specific gravity through the use of balances are known from the time of Archimedes [287 b.c.e.-212 b.c.e.], who knowing that gold was heavier than other common metals, developed a hydrostatic principle to deterimine if the King's crown was

[1463] Further historical information may be found in: A. Barclay., "Early technical balances," *Sands, Clays & Minerals*, **3** (1938), no. 3, pp. ??-??. • Robert T. Gunther., *Historic instruments for the advancement of science.* Oxford, Oxford University Press, 1925. [4], 90 p., illus. [Describes among others F. Hawksbee's hydrostatic balance of 1710, which still survives.]

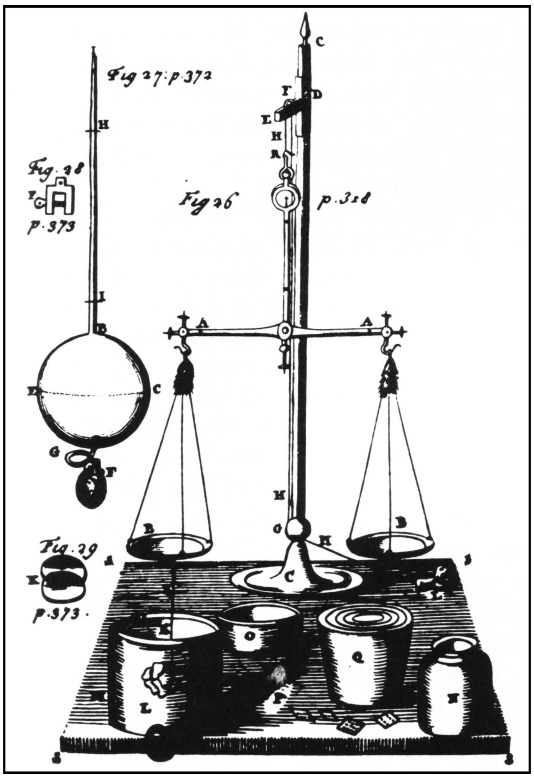
actually pure gold. By weighing the crown in air and then seeing how much water the crown displaced when submerged, Archimedes was able to calculate its density. Using the principles of Archemides, in the Near and Middle East, Arab researchers measured the specific gravity of precious stones, and were able through this property to distinguish authentic gems from imitations.[1464]

With broader research into scientific matters that came in the seventeenth century, hydrostatic balances were developed that used the principle of Archimedes to help determine the density of an object. By immersing a body in a liquid it is buoyed up by a force equal to the weight of the liquid displaced. These balances are also used to weigh objects in air and then in water, and thus determine their specific gravity.

Such instruments had a very practical application. As the economy of Europe industrialized, the counterfeiting of coins from alloys of inferior metals became an issue. For determining the authenticity of the money, many handheld scales used to weigh coins were produced. In these devices the coin was attached to pinchers that suspended the token. It would then first be weighed in air and then water. The calculation of the density, which could have been learned from lectures and illustrated booklets was easily calculated.

Interest in the composition of other substances led to the development of other balances with increased sensitivity that could be used to calculate an objects density. The great English chemist Robert Boyle used the principle of Archimedes when he designed a hydrometer balance around 1675.[1465]

F. Hawksbee of London who is regarded as the inventor of the double barreled air pump devised in circa 1710 a hydrostatic balance for determining the specific gravity of solids and liquids using a discshaped counterpoises, glass wieght and bucket.[1466] It is the oldest such




Boyle's Hydrostatic Balance, c1680

balance known to have been used in scientific work that survives, and is still on exhibit in the Ashmolean Museum in Oxford.

The first important modern scientific encyclopedia published by John Harris contains an article on "Hydrostaticall Balance," that explains its theory and operation.[1467]

The need of the state to standarize weights and measures prompted the development of new instruments, including hydrostatical balances.[1468]

In the early 1820s, Thomas Charles Robinson produced hydrostatic balances that were precise and inexpensive. With a delicate, openwork 5 in. beam and three pans it was accurate to one-hundredth of a grain (0.0006 g). The provision of a third pan on short

[1464] E. Wiedemann., "Beiträge zur Geschichte der Naturwissenschaften XXX. Zur Mineralogie in Islam," *Sitzungsberichte der Physikalisch-medizinischen Sozietät in Erlangen*, **44** (1912), p. 205-256.

[1465] Robert Boyle., "??????????," *Philsophical Transactions*, **10** (1675), 329.

[1466] R.T. Gunther., *Historic instruments for the advancement of science*. Oxford, Oxford University Press, 1925.

[1467] John Harris., "Hydrostaticall Balance," in: *Lexicon Technicum; or, An Universal Dictionary of Arts and Science*, London, 1710, **2**.

[1468] George Evelyn Shuckburgh., "An Account of Some Endevours to Ascertain a Standard of Weight and Measure," *Philosophical Transactions of the Royal Society*, **38** (1798), p. 133-182.

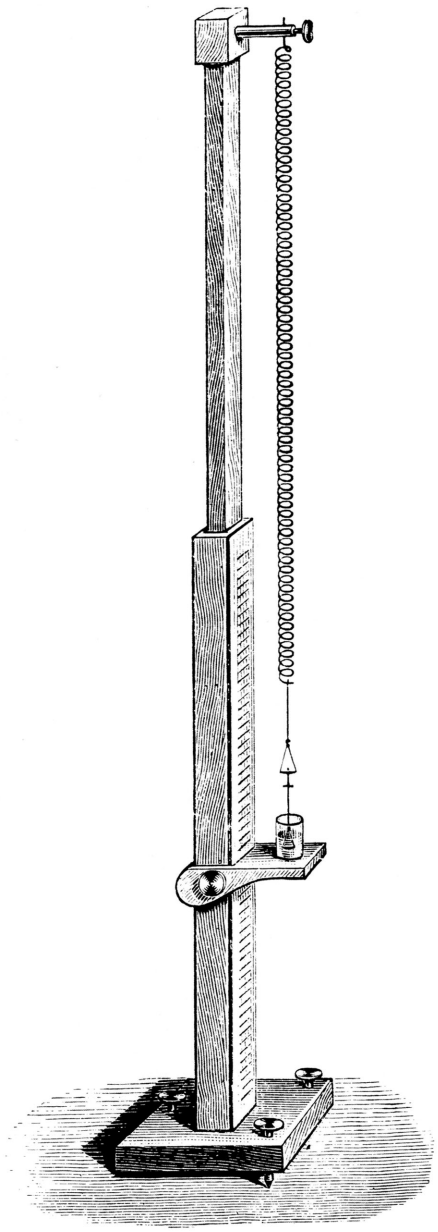
strings made the balance dual-purpose. The strings were soon replaced by fine platinum chains that were in turn replaced by pans with fixed bows and a hook under the top of the bow. A more specialized design had one-half of the beam evenly divided to take large calibrated riders shaped like horseshoes and a thermometer in a plummet of known mass to allow for corrections to be made for the temperature of the water.[1469]

1826-Robert Hare invented the 'litrameter' (also called 'Hare's apparatus') for determining the specific gravities of liquids as well as a hydrostatic balance similar to Mohr's.[1470]

In 1864, Philipp Gustav von Jolly devised a simple balance to ascertain the data needed to calculate the specific gravity.[1471] The instrument consists of a spiral spring at the lower end of which are suspended two pans or wire baskets. Upon the movable stand rests a beaker filled with water. The mineral whose specific gravity is to be determined is then placed on the pan or basket, and a measurement taken. The platform is then raised until the object is properly immersed in the water, and another measurement is taken. In the "Jolly Balance", as it became known, the specific gravity is determined by noting the amount of spring lengthening when the mineral is placed weighed in air ($w$), and the amount when it is immersed in water ($w'$). The specific gravity ($G$) is then calculated by the equation:

$$G = \left( \frac{w}{(w - w')} \right)$$

Improvements on Jolly's original invention were devised by C.E. Linebarger,[1472] A most excellent balance of this type, embodying several improvements upon the usual form



Jolly Type Balance, c1870

invented by Jolly, is that devised by Mr. C.E. Linebarger, and made by the Chicago Laboratory Supply and Scale Company

Edward H. Kraus modified Jolly's original balance, adding principally a scale attached to the side to help with the calculations.[1473] The first important

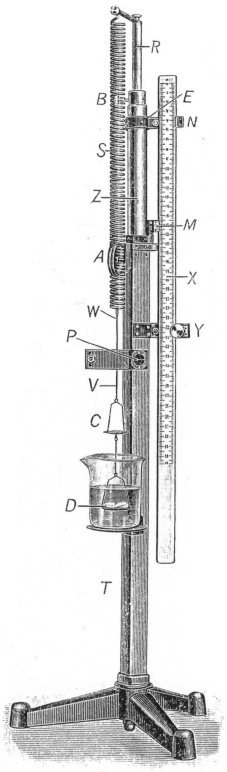
[1469] W.T. Brande., "Description of the Balance Represented in Plate V fig 1," *Quarterly Journal of Science Literature and the Arts*, **11** (1821), p. 280-281 and **12** (1822), p. 40-41.

[1470] Robert Hare., "On specific gravity," *American Journal of Science*, **11** (1826), p. 121-132.

[1471] P.G. von Jolly., "Eine Federwage zu exacten Wägungen," *Sitzungsberichte math.-phys. Cl. Ak. Wiss. München*, **1** (1864), p. 162-166.

[1472] C.E. Linebarger., "A new form of the spiral spring balance," *Physical Review*, **11** (1900), p. 110-111.

[1473] E.H. Kraus, "A new Jolly balance," *American Journal*

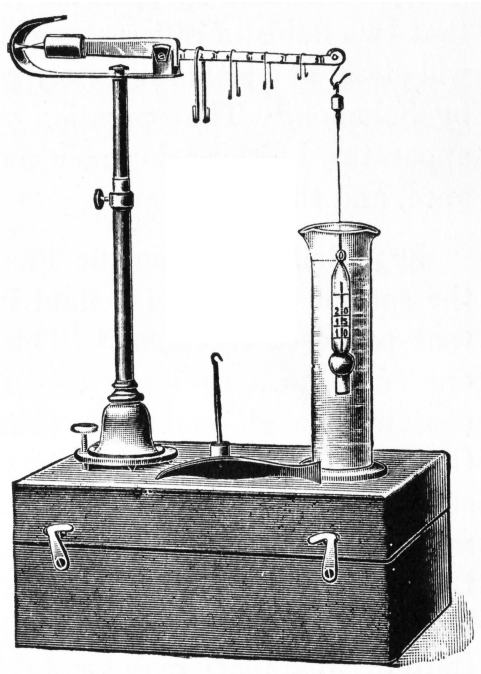



Kraus' Balance, 1911

modification of the spiral spring balance, devised by Jolly, was introduced by Linebarger in 1900, whose improved balance has since been used rather extensively. The balance to be described has several new features, of which the recording of the elongations of the spiral spring and the reducing of the number of readings necessary to determine the specific gravity are the most important.

The balance consists of the square upright tube T to which the fixed vernier M and the movable graduated scale X are attached, as shown in the accompanying figure. A second tube Z is movable within T by means of the miiled-head A. The movable vernier N is attached to Z by the arm E. The screw B controls the rod R, movable within the tube Z. From R the spiral spring S and scale pans C and D are suspended, the thin wire rods W and V connecting the spring and scale pans with the pointer P, which swings freely in front of a small circular mirror.

Apparently, at least one example of the Kraus instrument was made by Ralph Miller, "whose skill and experience as an instrument-maker were largely drawn upon in perfecting the balance." He was employed by Eberbaeh & Son Company, manufacturers and importers of scientific apparatus, Ann Arbor, Michigan.



Westphal's Balance, c1883

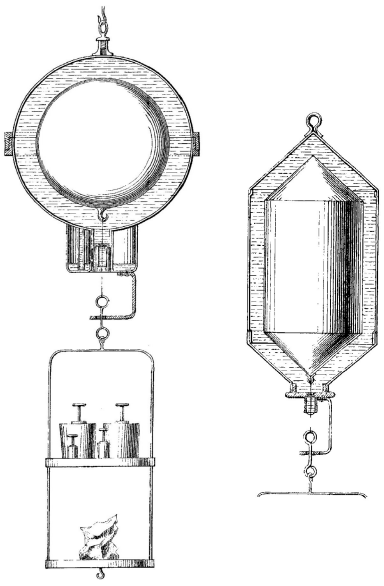
Carl Friedrich Mohr introduced a balance designed to indicate directly by means of a rider aparatus the specific gravity of solids or liquids. In 1883 the firm of Georg Westphal of Celle improved upon this idea and introduced their balance for conveniently determining the specific gravity of a liquid, and hence of a mineral when it is immersed in a heavy solution.[1474] It consists essentially of a graduated steelyard arm, upon which the weights, in the form of riders, are placed. These must be so adjusted that the sinker is freely suspended in the given liquid while the index at the end points to the zero of the scale and shows that the arm is horizontal. The graduation

*of Science*, **31** (1911), p. 561-563.; German translation, "Eine neue Jolly'sche Federwage zur Bestimmung des spezifischen Gewichts", *Centralblatt für Mineralogie*, **1911**, p. 366-368, illus.

[1474] Partington, *History of Chemistry*, 1964, **4**, 317.

usually allows of the specific gravity being read off directly without calculation.

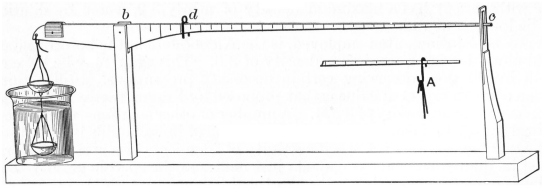
A cheap balance was created for use in courses of elementary chemistry. This balance–called the Chaslyn balance–resembles in form the familiar Westphal balance for specific gravity determinations. It has a capacity of 111 grams and is sensitive to 0.01 gram when loaded. It would seem to be admirably adapted to the purpose.[1475]



Jolly's Balance, 1888

John Jolly developed a new hydrostatic balance that he used to determine the specific gravities of minerals.[1476] Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx. Xxx xxxxx xx xxxxx.

If the mineral fragment is too small to be thus determined, or if it is in a owdered state, its specific gravity maybe obtained, as suggested by Penfield,[1477] by placing it in a small glass tube, closed at one end, and having a platinum dre at the other by which to suspend it. The fragments are first weighed dry. They are then boiled in water to remove all air, are transferred to the tube, which is suspended from a balance, and are weighed immersed in water. The weight of the tube in water without the mineral is subtracted from the ormer weight to give the weight in water. The specific gravity is found by the same formula as before.




Penfield's Balance, 1895

A beam balance described by Samuel Penfield is another very simple and quite accurate device for measuring the specific gravity.[1478] It is illustrated in Fig. 506, which will make clear its essential parts. The beam is so balanced by a weight on its shorter end that it is very nearly in equilibrium when the lower pan is immersed in water. An exact balance is then obtained by the small rider d. When the beam is once balanced this rider is kept stationary and its position disregarded in the subsequent readings. The mineral is first placed in the upper pan and the beam balanced by another rider of such a weight that its position will be near the outer end of the beam.

In 1900, the first major modification to Jolly's original spiral balance was published by Linebarger.[1479]

[1475] C. E. Linebarger., *Journal of the American Chemcial Society*, **21**, p. 31-33.

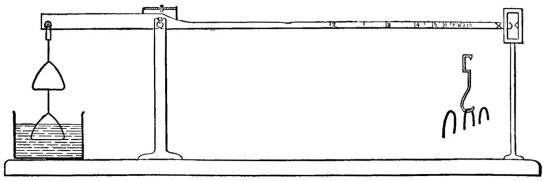
[1476] John Jolly., "On a hydrostatic balance," *Philosophical Magazine*, 5th series, **26** (1888), p. 266-72, plate 2.

[1477] S. L. Penfield: Ueber einige Verbesserungen der Methoden zur Trennung von Mineralien mit hohem sped fischen Gewicht. Zeitschr. f. Kryst., XXVI (1896), 134-137.

[1478] Samuel Penfield., "???????," *American Journal of Science*, **32** (1911), 425. [NOT SURE IF THIS IS THE PAPER... DESCRIBED FIRST IN 1895.] • Dana, *Textbook*, 1922, p. 197.

[1479] Linebarger, ??., "???????," *Physical Review*, **11** (1900), p. 110.

Thomas Henry Digges La Touche devised an instrument that could determine the specific gravity of large rocks specimens.[1480]



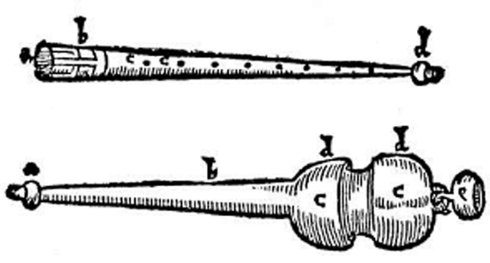
Roger's Balance, 1911

A very convenient balance which gives at once the value of the specific gravity from the reading on a graduated arm, was designed by Rogers.[1481]

### 14.3.2 Hydrometers

**REWORK:** A hydrometer is a device for measuring the specific gravity of a liquid relative to water, which is assumed to have a specific gravity of 1.000... Or, it can be thought of as measuring the density of the liquid in grams per cubic centimeter.

The more conventional hydrometer is a tube, weighted at the bottom to float upright, which sinks to various depths depending on the density of the liquid. The device used to measure the freezing point of antifreeze mixtures is a familiar example of a hydrometer used in an industrial setting. Brewers, wine-makers and distillers use hydrometers to measure the percentage of alcohol in their products. They were also adopted to measure the specific gravity of minerals.



Libavius' Hydrometer, c1600

The great Libavius used hydrometers in his chemical work. They were made of glass and illustrated in his influential *???????* (1597).

**Kobell** p. 115:

The accomplishments of Richard Kirwan to define the specific gravity of mineral species exactly, and for this purpose he used the data of Mathurin Jacques Brisson, which at the time was considered to be complete and superior. In his mineral examinations he utilzed a hydrometer of the form invented by William Nicholson. Haüy had earlier reported on this insturment with an accompanying illustration.[1482] Its use was described as:

> One loads on the plate A of the scale, which floats in a glass cylinder filled with distilled water, ¡KOBELL, p. 116¿ until it sinks on the ...Feilstrich... at b, imposed by the sample. By drawing off of the amount of the weight from the first load one learns the absolute weight of the sample = p. This sample is then layed on the surface of the cone at E, in doing so, the scale is raised and then it states to the renewed sinks until b forces weight of the lose in weight in water = q. Specific gravity is then defined s = p/q.

Nicholson's hydrometer differs from other hydrometers in being totally submerged in use. The example at the left, from St. Mary's College in Notre Dame, Indiana, is pictured upside-down; in use all of the instrument except the small platform is immersed in the liquid. It is first placed in water and small weights loaded on the platform until the water level reaches a mark on the wire stem. The device is then placed in the unknown liquid, and loaded to the same line. The relative density of the unknown can then be obtained in terms of the mass of the hydrometer and the two sets of masses used to bring it to the reference line.

William Nicholson invented a hydrometer known as Nicholson's hydrometer,[1483] that was a modification of one described by Fahrenheit,[1484] which was similar to one

[1480] T.H.D. La Touche., "A specific gravity balance for large rock specimens," *Nature*, **77** (1908), p. 221.

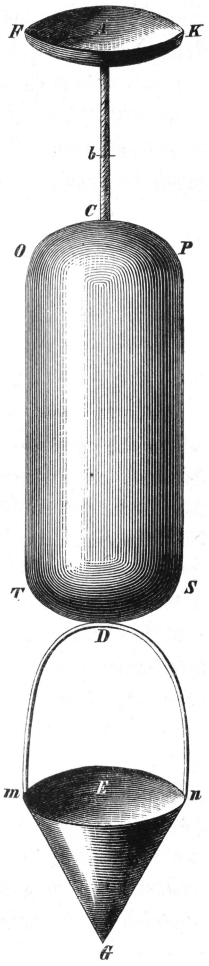
[1481] Austin F. Rogers., "A new specific gravity balance," *Science*, **34** (1911), p. 58-60.

[1482] *Journal d'Histoire Naturelle*, **1** (1792), ??-??, fig. 58. [German translation: *Journal der Physik*, edited by A.C. Gren, **5** (1792), ??-??]

[1483] William Nicholson, "Description of a new insturment for measuring the specific gravities of bodies," *Memoires, Manchester Society*, **2** (1787), 370-??.

[1484] Fahrenheit., "?????????," *Philosophical Transactions*, **33** (1724), 140 [spherical bulb].

described by Robert Boyle.[1485] It also used the principle of Archimedes.




Nicholson's Hydrometer, 1787

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1755-Jacob Faggot [1699-1777] gave an analysis of gunpowder by the hydrostatic balance.[1486]

1798-Jean Henri Hassenfratz published on hydrometry.[1487]

1785-Nicholson ...[1488]

1808-Atkins ...[1489]
1826 Robert Hare ...[1490]
1826 Another Hare ...[1491]
1828-Beudant ... [1492]
1846-Scheerer ... [1493]
1848-Rose ... [1494]
1856-Jenzsch ... [1495]
1859-Schröder ...[1496]
1859-Gadolin ... [1497]
1863-Tschermak ...[1498]

### 14.3.3 Pycnometer[1499]

**REWORK:** If the mineral is in the form of grains or small fragments, the specific gravity may be obtained by use of the pycnometer.[1500] This is a small bottle having a stopper that fits tightly and ends in a tube with a very small opening. The bottle is filled with distilled water, the stopper inserted, and the overflowing water carefully removed with a soft cloth and then weighed. The mineral whose density is to be determined is also weighed in air. Lastly the bottle is weighed with the mineral in it and filled with water as described above. The

[1485] Robert Boyle., "??????????," *Philsophical Transactions*, **10** (1675), 329.

[1486] KAH., **16** (1755), 96.

[1487] Jean Henri Hassenfratz., "????," *Annals Chimie*, **26** (1798), 7, 132, **27** (1798), 116 & **28** (1798), 282.

[1488] William Nicholson., "Description of a new insturment for measuring the specific gravities of bodies," *Mém. Lit. Phil. Soc. Manchester*, **2** (1785), 370-380.

[1489] G. Atkins., "Description of a new hydrometer for determining the specific gravity of both solids and liquids," *Philosophical Magazine*, **31** (1808), p. 254-258.

[1490] Robert Hare., "On specific gravity," *American Journal of Science*, **11** (1826), p. 121-32.

[1491] Robert Hare., "Opinion on hydrometers," *American Journal of Science*, **11** (1826), p. 115-19.

[1492] F.S. Beudant., *Poggendorff's Annalen*, **14** (1828), 474.

[1493] Scheerer., *Poggendorff's Annalen*, **67** (1846), 120.

[1494] G. Rose., *Poggendorff's Annalen*, **73** (1848), 1 & **75** (1848), 403.

[1495] Jenzsch., *Poggendorff's Annalen*, **99** (1856), 151.

[1496] Schröder., *Poggendorff's Annalen*, **106** (1859), 226. • *ibid.*, *Jahrbuch für Mineralogie*, 1873, 561, 932 & 1874, 399, ...

[1497] Gadolin., *Poggendorff's Annalen*, **106** (1859), 213.

[1498] Tschermak., *Ber. Ak. Wien*, **47** (1863), no. 1, 292.

[1499] Further historical information may be found in: Dana, *Textbook*, 1922, p. 197-198. • Albert Johannsen, *Manual of petrographic methods*. Second edition. New York, McGraw-Hill Book Co., 1918. [Chapter 38, "Determination of Specific Gravity."]

[1500] James P. Joule and Lyon Playfair., "Researches on atomic volume and specific gravity," *Jour. Chem. Soc. London*, **1** (1849), p. 123. • Earl of Berkeley., "On an accurate method of determining the densities of solids," *Mineralogical Magazine*, **11** (1895), p. 64-68. • W. Leick., "Lieber speeifische Gewichtsbestimmung," *Mittheil, naturwiss. Ver. Neu Vorpommern und Rügen*, **27** (1895).

weight of the water displaced by the mineral is obviously the difference between this last weight and that of the bottle filled with water plus the weight of the mineral. The specific gravity of the mineral is equal to its weight alone divided by the weight of the equal volume of water thus determined. Where this method is followed with sufficient care, especially avoiding any change of temperature in the water, the results may be highly accurate.




Pycnometer (c1900)

If the mineral forms a porous mass, it may be first reduced to powder, but it is to be noted that it has been shown by Gustav Rose that chemical precipitates have uniformly a higher density than belongs to the same substance in a less finely divided state.[1501] This increase of density also characterizes, though to a less extent, a mineral in a fine state of mechanical subdivision. It is explained by the condensation of the water on the surface of the powder.

### 14.3.4 Heavy Liquids[1502]

**REWORK:** It was recognized in the late nineteenth century, that liquids of varying densities could be used to determine a minerals specific gravity. If a mineral fragment floated in a liquid of known density, the density of the mineral must be less than that of the liquid. For mineralogical purposes, a series of such fluids were used to determine a quick density check for an unknown mineral.

Use of Liquids of High Density. — It is often found convenient both in the determination of the specific gravity and in the mechanical separation of fragments of different specific gravities (e.g., to obtain pure material for analysis, or again in the study of rocks) to use a liquid of high density - that is, a so-called heavy solution. One of these is the solution of mercuric iodide in potassium iodide, called the Sonstadt or Thoulet solution. When made with care it has a maximum density of nearly 3*2, which by dilution may be lowered at will.

A second solution, often employed, is the Klein solution, the borotungstate of cadmium, haying a maximum density of 3'6. This again may be lowered at will by dilution, observing certain necessary precautions. Still a third solution of much practical value is that proposed by Brauns, methylene iodide, which has a specific gravity of 3*324. A number of other solutions, more or less practical, have also been suggested.! When one of these liquids is to be used for the determination of the specific gravity of fragments of a certain mineral it must be diluted until the fragments just float and the specific gravity then obtained, most conveniently by the Westphal balance.

When, on the other hand, the liquid is to be used for the separation of the fragments of two or more minerals mixed together, the material is first reduced to the proper degree of fineness, the dust and smallest fragments being sifted out, then it is introduced into the solution and this diluted until one constituent after another sinks and is removed. For the convenient application of this method a suitable tube is called for and certain precautions must be observed; compare the papers noted in the literature; especially one by Penfield. Johannsen, *Manual of Petrographic Methods*, (p. 519-529), gives in detail an account of the various solutions, the methods

[1501] G. Rose., *Poggendorff's Annalen*, **73** (1848), 1 & **75** (1848), 403.

[1502] Further historical information may be found in: Albert Johannsen, *Manual of petrographic methods*. Second edition. New York, McGraw-Hill Book Co., 1918. [Chapter 38, "Determination of Specific Gravity."] • Aleksandr P. Karpinski., Петрографичечкаиа замбтки [Petrographic Notes. 1) On leucoxene. 2) On heavy fluids used in the mechanical analysis of mineral mixtures. 3) On methods of quantitative estimation of quartz in mineral strata by proximate chemical analysis.] *St. Petersburg, Com. Géol. Bull.*, **3** (1884), p. 263-280, 321; Abstracted in *Neues Jahrbuch für Mineralogie*, **1886**, part 1, p. 263-264.

of their preparation, etc.[1503]

See Dana's *Textbook*, 1903, p. 160.

Researchers that studied heavy solutions were: Thomas Dewhurst (1909),[1504] Ernst Sommerfeldt (1910).[1505]

Other Heavy Solution References:

[1506] [1507] [1508] [1509] [1510] [1511] [1512] [1513] [1514] [1515] [1516] [1517]

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For determining the specific gravity of minerals, it was found that a variety of dense liquids could be used. See Dana's *Textbook* for references.

Methods of Determining Specific Gravity

A number of experimental methods for determining the specific gravities of solids, liquids, and gases have been devised. A solid is weighed first in air, then while immersed in water; the difference in the two weights, according to Archimedes' principle, is the weight of the water displaced by the volume of the solid. If the solid is less dense than water, some means must be adopted to fully submerge it, e.g., a system of pulleys or a sinker of known mass and volume. The specific gravity of the solid is the ratio of its weight in air to the difference between its weight in air and its weight immersed in water.

Two methods are commonly used for determining the specific gravities of liquids. One method uses the hydrometer, an instrument that gives a specific gravity reading directly. A second method, called the bottle method, uses a "specific-gravity bottle," i.e., a flask made to hold a known volume of liquid at a specified temperature (usually 20°C). The bottle is weighed, filled with the liquid whose specific gravity is to be found, and weighed again. The difference in weights is divided by the weight of an equal volume of water to give the specific gravity of the liquid. For gases a method essentially the same as the bottle method for liquids is used. Specific gravities of gases are usually converted mathematically to their value at standard temperature and pressure

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Instead of determining the specific gravity of a mineral by weighing it in water, the determination may be made by immersing it in a liquid of known density and aoting whether it sinks or floats. For such determinations a series of fluids of different specific gravities, or two fluids of widely different specific gravities, may be used.[1518] In the latter case the mineral to be determined is first placed in the heavier solution. If it floats, the lighter fluid is slowly added, with constant and thorough stirring, until the mineral begins to show signs of sinking. The lighter fluid is now added more slowly until a point is reached at which the mineral remains stationary for a short time at any depth at which it may be placed. That the point of equal density is being approached may te seen by the fact that, after stirring, the movements of the mineral particles are more sluggish, while flakes stand on their edges, and laths on their ends. When the specific gravity of the mineral and the fluid are equal, it is only necessary to determine that of the latter.

Various fluids have been suggested for the determination of density, but these so-called heavy solutions have been used more frequently for the mechanical separation of the different components of a composite rock than for the determination of specific gravity.

The first use of a heavy solution for the determination of density is ascribed by

[1503] Albert Johannsen., *Manual of petrographic methods*. Second edition. New York, McGraw-Hill Book Company, Inc., 1918. xxviii, 649 p. illus., plates, diagrams.

[1504] Thomas Dewhurst., "The determination of specific gravity and the use of heavy liquids," *Belfast Proceeedings Nat. F. Cl.* Series 2, **6** (1909), p. 191-192.

[1505] Ernst Sommerfeldt., "Eine Erweiterung der Suspensionsmethode zur Bestimmung des spezifischen Gewichts," *Centralblatt für Mineralogie*, **1910**, p. 482-488.

[1506] Sonstadt. *Chem. News*, 29, 127, 1874.

[1507] Thoulet. *Bull. Soc. Min.*, 2, 17, 189, 1879.

[1508] Bréon. *Bull. Soc. Min.*, 3, 46, 1880.

[1509] Goldschmidt. *Jb. Min., Beil.-Bd.*, 1, 179, 1881.

[1510] D. Klein. *Bull. Soc. Min.*, 4, 149, 1881.

[1511] Rohrbach. *Jb. Min.*, 2, 186, 1883.

[1512] Gisevius. *Inaug. Diss.*, Bonn., 1883.

[1513] Brauns. *Jb. Min.*, 2, 72, 1886; 1, 213, 1888.

[1514] Retgers. *Jb. Min.*, 2, 185, 1889.

[1515] Salomon. *Jb. Min.*, 2, 214, 1891.

[1516] Penfield. *Am. J. Sc*, 60, 446, 1895.

[1517] Merwin. *Am. J. Sc*, 32, 425, 1911.

[1518] See caution in regard to the use of heavy solutions, Art. 497.

Kalkowsky[1519] to Scheibler who used, in 1861, sodium metatungstate with a specific gravity of 3.02. According to the same authority Marignac, in 1862, used a solution of sodium silico-tungstate with a specific gravity of 3.05. In the same year Schaffgotsch[1520] used an aqueous solution of acid mercuric nitrate. Into this solution the mineral was placed. If it floated, dilute nitric acid was added until the mineral slowly sank, whereupon a glass rod was dipped into the concentrated solution of acid mercuric nitrate and placed in the test glass enough times to cause the mineral to be suspended. The temperature of the solution was now raised to 17 1/20 C. by warming the beaker with the hand, and the specific gravity of the solution determined. On account of the acid character of the solution it acts upon many minerals, and was but little used. It canr not be diluted with water on account of the precipitation of a basic salt.

454. Sonstadt (or Thoulet) Solution (1874, 1877).-The so-called Thoulet solution, with a maximum specific gravity of 3.196, is an aqueous solution of potassium mercuric iodide. It was first described by Sonstadt,[1521] in 1874, and his name should be given to it. He used it for the determination of the specific gravities of alkali salts, and prepared it by making a saturated solu-tion, at room temperature, of iodide of potassium, into which as much mercuric iodide was stirred as would dissolve.

Though the Sonstadt solution was used by Church[1522] in 1877, it did not become generally known until Thoulet[1523] published his experiments in 1878-9. It became still more widely known after Goldschmidt[1524] published his careful investigations of the properties of the solution in 1881.

To prepare the solution, 80 c.c. of cold distilled water are taken, and in it 270 grm. of mercuric iodide (Hgl2) and 230 grm. of potassium iodide (KI) are dissolved by stirring. The solution is placed in a porcelain evaporating dish on a water-, not sand-bath, and is evaporated until a crystalline film forms on the surface, or until a crystal of tourmaline ($\mathcal{L} = 3.1$) or fluorite (G = 3.i8) floats. Upon cooling, the solution contracts, and the specific gravity rises to its maximum of 3.196. Needles of hydrous potassium mercuric iodide may crystallize out upon cooling, but if sufficient liquid has been prepared, the clear portion may be decanted. Should it be necessary to use all of the fluid, a, few drops of water added will cause the crystals to be

Klein Solution (1881).-The heavy fluid proposed by D. Klein[1525] is an aqueous solution of cadmium borotungstate. The process of preparation is quite complicated, and is given by Edwards[1526] as follows: The apparatus necessary are two large porcelain evaporating dishes 10 in. in diameter, two 6 in. in diameter, and two 3 in. in diameter, two beakers 10 in. deep and two 6 in. deep,

[1519] Review by Ernst Kalkowsky of Aleksandr P. Karpinski., Петрографичечкаиа замбтки [Petrographic Notes. 1) On leucoxene. 2) On heavy fluids used in the mechanical analysis of mineral mixtures. 3) On methods of quantitative estimation of quartz in mineral strata by proximate chemical analysis.] *Izvestiia Geologicheskago Komiteta = Bulletin du Comité Géologique* (St. Petersburg), **3** (1884), p. 263-280, 321; Abstracted in *Neues Jahrbuch für Mineralogie*, **1886**, part 1, p. 263-264. In this work, written in the Russian language, Karpinskij gives a history of the discovery and use of heavy fluids for mechanical separation of rock constituents. In the review the original reference to Scheibler's work, if published, is not given.

[1520] F. G. Schaffgotsch: Ermittelung des Eigengewichts fester Körper durch Schweben. Pogg. Ann., CXVI (1862), 279-289.

[1521] E. Sonstadt: Note on a new method of taking specific gravities, adapted for special cases. Chem. News, XXIX (1874), 127-128.

[1522] A. H. Church: A test of specific gravity. Mineralog. Mag., I (1877), 237-238.

[1523] J. Thoulet: Separation des elements nonferrugineux des roches fondee sur leur difference de poids specifique. Comptes Rendus, LXXXVI (1878), 454-456. Idem: Separation mechanique des elements mineralogiques des roches. Bull. Soc. Min. France, II (1879), 17-24.

[1524] V. Goldschmidt: Ueber Verwendbarkeit einer Kaliumquecksilberjodlösung bei miner-alogischen und petrographischen Untersuchung. Neues Jahrb., B.B. I (1881), 179-238.

[1525] Daniel Klein: Sur la separation mecanique par voie humide des mineraux de densite. inferieure ä 3.6. Bull. Soc. Min. France, IV (1881), 149-155. Idem: Sur une solution de densite 3.28 propre d Vanalyse immediate des roches. Comptes Rendus, XCIII (1881), 318-321. Review by H. Rosenbusch of both preceding articles. Neues Jahrb., 1882 (II), 189-191.

[1526] W. B. D. Edwards: On the preparation of a cheap heavy liquid for the separation of minerals. Geol. Mag., VIII (1891), 273-275.

and a glass funnel. The operation should be performed under a hood to carry off the fumes. The weights given below will make 160 grm. of cadmium borotungstate or about 50 c.c. of the solution.

Rohrbach Solution, (1879, 1883). According to Karpinskij,[1527] solution of barium-mercuric iodide was used for the determination of pecific gravities by Suschin in 1879, and described by Karpinskij in 1880.[1528] the publication, however, being in the Russian language, was seen by few ivestigators and it was not until 1883, when Rohrbach[1529] rediscovered it, hat the solution came into general use.

Methylene Iodide (Brauns) (1886). So long ago as 1873, Sonstadt[1530] used ethyl iodide (C2H5I, with G = i.o3), prepared from commercial methy-lated spirits, therefore containing a few per cent, of methyl iodide, and having a density of about 2.0. For the determination of density he diluted it with bisulphide of carbon or chloroform, preferably the former since it is less vola-tile. To prevent the liquid from becoming discolored by the separation of iodine, he placed in it magnesium (or copper) wire or filings. The first use made of methylene iodide (CH2I2) was by Brauns,[1531] in 1886. This substance is a thin, light yellow fluid of high refractive index, boiling at 1800 C. with partial decomposition, and freezing at 50 C. It can be diluted with neither water nor alcohol, but may be, in all proportions, with benzol. It is unaltered by exposure to the atmosphere and is slow to evaporate when concentrated, so that one can work for hours with no apparent change in the refractive index or specific gravity. When diluted it changes its refractive index and density rapidly by the evaporation of the benzol. It does not act upon the skin, metals, nor carbonates, but is decomposed by sulphur. The cost is rather more than the other heavy fluids already mentioned, being, at the present time, about $3.25 per 100 grm., duty free, as against $1.65 for the same amount of Sonstadt's.

Retgers' Heavy Fluids (1889). A great number of experiments were made by Retgers[1532] to obtain fluids having higher densities than any previously used. He found that after concentrating Sonstadt's solution on the water-bath until a surface film was produced, he could, by stirring, dissolve flakes of iodine in it, and thus obtain a black, opaque liquid. Upon cooling, a certain part of the iodine separated, but the decanted liquid itself had a specific gravity of 3.30-3.40.

460. Schroeder van der Kolk (1895). Schroeder van der Kolk,[1533] in 1895, used bromoform as a heavy solution for the separation of the constituent minerals of sands. It has a density of 2.88 and is useful for the separation of many minerals. It is much less expensive than methylene iodide, costing about 10 cents an ounce. Its melting-point is 2.50 C, its boiling-point 1510, and its refractive index by sodium light at 150, 1.588. It is not decomposed by air or light. It should be used without dilution.

461. Muthmann (1898). Muthmann[1534] used symmetrical acetylene tetrabromide, with a specific gravity of 3.01, as a heavy solution. Its melting-point is below - 200 C. and its boiling-point 13 70 under a pressure of 3.6 of mercury. It may be diluted with ether, benzol, or toluol in any proportions, and may be restored to its original density by evaporation. It is decomposed by neither air nor minerals, not even by ores. Since its density is almost

[1527] Review by Ernst Kalkowsky of A. Karpinskij. Cit. supra.

[1528] Trudy St. Petersburgh Obschtsch. jestjestw., XI (1880), 146.

[1529] Carl Rohrbach: Ueber eine neue Flüssigkeit ion hohem specifischen Gewicht, hohem Brechungsexponenten und grosser Dispersion. Wiedem. Ann., N. F. XX (1883), 169-174. • *ibid.*, Ueber die Verwendbarkeit einer Baryumquecksilberjodid-Losung zu petrographischen Zwecken. Neues Jahrb., 1883 (II), 186-188.

[1530] Op. cit.

[1531] R. Brauns: Ueber die Verwendbarkeit des Methylenodids bei petrographischen und optischen Untersuchungen. Neues Jahrb., 1886 (II), 72-78. C. Chelius: Zur Benutzung des Methylen]odids. Notizbl. Ver. f. Erdk. Darmstadt, 1890 (4), 16.

[1532] J. W. Retgers: Ueber schwere Flüssigkeiten zur Trennung von Mineralien, Neues Jahrb., 1889 (II), 185-192.

[1533] J. L. C. Schroeder van der Kolk: Beitrag zur Kartirung der quartären Sande. Neues Jahrb., 1895 (I), 272-276, especially 274.

[1534] W. Muthmann: lieber eine zur Trennung von Mineralgemischen geeignete schwere Flüssigkeit. Zeitschr. f. Kryst., XXX (1898), 73-74

exactly 3.0, it is useful as one of a series of density fluids. Minerals removed from this fluid may be cleaned by washing with ether. It costs less than 10 cents an ounce.

Clerici[1535] examined numerous thallium salts of the organic acids and found the one best adapted as a heavy solution to be hallium formiate, aqueous solutions of which are colorless and free-flowing s water. The amount of the salt necessary for saturation depends upon the emperature, 5.0 grm. being soluble in 1 c.c. of water at io° C. The density if the saturated solution varies with the amount of salt dissolved (Fig. 719), eing 2.58 at - io° C, 2.86 ato°, 3.14 at io°, 3.40 at 200, 3.64 at 300, 3.87 at o°, 4.11, at 500, 4.32 at 6o°, 4.50 at 700, 4.67 at 8o°, and 4.76 at oo°. At 950 hallium formiate melts and has a density great enough to float ilmenite. rhe solution is miscible with water.

Joly[1536] determined the specific gravity of mineral fragnents by placing them on a piece of previously weighed paraffine, careully melting them in, and proceeding as by the method of Thoulet.

464. Hubbard (1887). A method for approximately determining the specific gravity of a mineral was given by Hubbard.[1537] He simultaneously placed the unknown mineral fragments and a number of other minerals of known density in a cadmium borotungstate solution (6 = 3.3). By noting the rapidity with which the different minerals sank, he determined their relative densities.

465. Streng (1887). To determine the specific gravity of minerals heavier than the immersion fluid, Streng[1538] made use of small glass cups constructed from glass tubing. They were made as thin as possible, from 5 to 6 mm. deep a.nd 5 mm. in diameter at the top. To the bottom of each, three platinum wires were fused to serve as counterpoises to keep the vessel erect. Into the cup a fragment of the mineral to be tested was placed, and the cup was filled with the heavy solution, all bubbles being removed by means of a piece of platinum wire. The cup and mineral were now placed in the heavy solution which was diluted, with constant stirring, until they were suspended.

Retgers[1539] pointed out that in Streng's method errors were likely to occur through the incomplete mixing of the heavy solution during dilution, and through the probability that the solution within the cup remains heavier than that in the surrounding beaker. The absolute weight of the cup is also too great, as compared with the mineral, to give very accurate results, except with very large fragments. To remedy this, Retgers made glass clips by bending fine glass threads into the form of horseshoes, the spring of the glass keeping the ends together or pressed against the mineral fragment whose specific gravity is to be determined. A great number of these clips of various sizes and forms may quickly be constructed, their absolute weight and specific gravity being determined once for all.

In determining the density of a mineral by the use of these glass clips, it is essential that they be chosen no larger than necessary to give the desired buoyancy. The formula to be used is the same as in Streng's method.

Owing to the fragility of Retgers' glass floats, Behr[1540] replaced them by glass tubes, such as are used in organic chemistry for the determination of melting-points. These tubes were shortened to 10 or 12 mm., and into one was inserted the crystal whose density was to be measured, its absolute weight having been determined previously. To prevent the crystal from slipping out, each end of the tube was slightly constricted by heating it. The

[1535] Enrico Clerici: Preparazione di liquidi per la separazionc dei minerali. Riend. Acad. Lincei. Roma (Ser. 5), XVI (1907), 1 Semsetre, 187-195.

[1536] Joly: On a method of determining the specific gravity of small quantities of dense or porous bodies. Phil. Mag. XXVI (1888), 29-33. Idem: On a method of determining the specific grazity of small quantities of dense or porous bodies. Proc. Roy. Dublin Soc, V (1886), 41-47.

[1537] L. Hubbard: Beitrage zur Kenntnis der Noseanfuhrenden Auswürflinge des Laacher Sees. T. M. P. M., VIII (1887), 390.

[1538] A. Streng: lieber die Bestimmung des specifischen Gewichts schwerer Mineralien, 23er. oberhess. Gesell, Giessen, XXV (1887), 110-113.

[1539] J. W. Retgers: Die Bestimmung des sped fischen Gewichtes in Wasser loslichen Salzen- Zeitschr. f. phys. Chemie, IV (1889), 189-196.

[1540] J. Behr: Beitrage zu den Beziehungen zwischen eutropischen und isomorphen Substanzen, Neues Jahrb., 1903 (I), 136-159, especially 143-146

specific gravity of the combination was now determined, and the true density computed by the formula given under Thoulet's method above.

The method of Goldschmidt[1541] for the determination of the specific gravity of the heavy solution, after dilution to the point of suspension of the mineral, is as follows: First enough of the solution is poured into a glass flask to reach a mark indicating exactly 25 c.c. The exact point may best be determined by filling the flask slightly above the mark, which should extend entirely around the neck, bring-ing it to the level of the eye so that the scratch appears as a straight line, and removing enough of the fluid, with a pipette or piece of filter paper, to bring the lower curve of the meniscus tangent to this mark. The flask and contents are now weighed together, after which the fluid is returned to the beaker containing the mineral, and notice is taken that the mineral is again suspended. It is again poured to the 25 c.c. mark, and again flask and fluid are weighed. The same process is repeated a third time. These results are now averaged. Should the values differ widely, the process is repeated a fourth time to see if an error has been made. Note particularly that the mineral is suspended between each reading, and that the flask is filled exactly to the mark each time. Should the mineral and fluid not be of exactly the same specific gravity at any reading, owing to evaporation or other cause, the density is corrected by adding a few drops of water or of concentrated solution.

The method with the Sprengel tube is very similar. The heavy liquid is sucked up into the tube to a mark indicating a known volume, the apparatus is hung from a balance by means of a platinum wire, and the tube and contained liquid are weighed (w). The weight of the tube alone iw'), and of the tube filled to the mark with distilled water iw"), are known

Sollas[1542] proposed a modification of the Sprelngel tube by connecting the two enlarged parts by a thin calibrated tube. The method otherwise is the same.

One of the simplest methods for the determination of the specific gravity of a liquid is by means of a balance originally manufactured by G. Westphal in Celle, and now generally known as the Westphal balance. It was first described by Cohen[1543]

An apparatus,based on the principle that two fluids of different specific gravities placed in communicating tubes will stand at heights inversely proportional to their densities, was designed by Salomon.[1544] The operation of determining the density of a fluid by this apparatus, however, is much more complicated than by the Westphal balance, and the results are less accurate.

## 14.4 Sclerometer (Hardness)[1545]

**REWORK:** The sclerometer (from the Ancient Greek skleros meaning "hard") is a mineralogist's (usually) instrument used to measure the hardness of materials. In mineralogy, it is an instrument used to accurately determine the hardness of minerals.

Exact Measurement of Hardness by the Selerometer. The most precise measurements of hardness yet possible are obtained by the method of Pfaff with the instrument known as the " Selerometer." The instrument is seen in Fig. 717 as constructed by Steeg and Reuter.

It consists of a horizontal goniometer-circle divided diiectly into single degrees, v, ith the crystal-adjusting apparatus carried immediately above it and terminating in a little tabular support on which the crystal can be cemented. The non-rotatable basal table and central axial cone for the independently rotatable circle and crystalholder is mounted

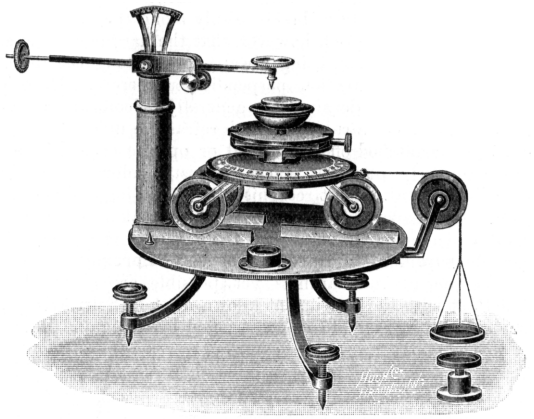
[1541] Goldschmidt: Ueber Verwendbarkeit einer Kaliumquecksilberjojidlb'sung bei mineralogischen und petrographischen Untersuchung. Neues Jahrb.,BB. I (1881) 197-199.

[1542] J. Sollas: On a separating apparatus for use with heaiy fluids. Proc. Roy. Dublin Soc, N. S., V (1886-7), 621-622.

[1543] E. Cohen: Ueber eine einfache Methode das specifische Gewicht einer Kalitimquecksilber-iodidlösung zu bestimmen. Neues Jahrb., 1883 (II), 87-89.

[1544] W. Salomon., Ein neuer Apparat zur Bestimmung des specifischen Gewichtes von Flüssigkeiten. Neues Jahrb., 1891 (II), 214-220.

[1545] Further historical information may be found in: Ulrich Burchard., "The sclerometer and the determination of the hardness of minerals," *Mineralogical Record*, **35** (2004), p. 109-120.



Sclerometer (c1910)

on three wheels rolling on three corresponding guiding rails. The ti averse is brought about by laying a convenient weight in a pan connected by a cord with the goniometer table, and passing over a pulley. The fixed tripod table which carries the rails is also fitted with a spirit level, and a vertical column rises from it near the edge, which carries the balance beam, to the end of one arm of which the scratching point is attached. Two alternative points are given, one of which is shown in position and the other lying on the tripod table ; one is of hardened steel and the other is of diamond. It is carried at that end of the balance beam which comes over the centre, a little pan for the reception of weights being arranged immediately above it, in order that the scratching may occur with a given pressure. The other arm of the balance carries an adjustable counterpoise for the weight of the pan and scratching point. An adjustable stop is arranged to prevent the point from cutting top deeply into the crystal. In order to provide for crystals of different sizes the supporting column of the balance is adjustable for height, by sliding in an outer pedestal column.

A similar instrument is also supplied by Fuess, the centring and adjusting movements for the crystal being the same as those on the No. 2a goniometer, but which is otherwise constructed on lines resembling those of the instrument shown in Fig. 717.

The crystal is fixed upon the adjusting apparatus with the face to be tested uppermost, and the load on the little pan above the diamond increased until the point of the diamond resting on the crystal surface just scratches it as the crystal is drawn underneath it by the traversing of the goniometer, under the influence of a weight in the pan suspended from the cord. After raising the diamond again the goniometer circle is rotated for some definite angle, and another scratch made, the process being repeated until the scratching effect for all kinds of azimuths of the crystal surface has been tested, the minimum load required to produce a scratch in each direction having been recorded. A drawing of the crystal face is then made, and lines drawn from the centre of it along each experimental direction, of a length proportional to the observed hardness, their terminations being arranged so as not quite to reach the boundary lines representing the crystal face; these terminations of the lines are then joined by a curve, the Curve of Hardness. Such a curve will exhibit the symmetry of the system. For instance, the curve of hardness on the face (111) of calcite perpendicular to the optic axis is a three-leaved rosette, with maxima 120° apart, and minima at the half-way positions; that for a cube face is a square with rounded corners or maxima, and with depressions or minima in the middle of each side. A somewhat more delicate and accurate modification of this method has also been introduced by Pfaff, according to which the load on the diamond point is kept constant at a weight adequate to effect a convenient depth of scratch, and the traverse is performed for a definite number of times, a hundred or more, the diamond being only allowed to come into operation during the movement in one and the same direction; the amount of material scratched off is then determined by the loss of weight of the crystal, which with its attached crystal-holder is carefully weighed before and after the experiment. The hardness is then considered to be inversely proportional to the weight of crystal dust thus removed.

A delicate form of sclerometer for use with the crystallographic microscope, such as the Dick microscope or the No. 1 Fuess



On the History of Mineralogy & Crystallography from Beginnings through 1919
by Curtis P. Schuh, Tucson, AZ—Edit Draft. [1200dpi]
NOT FOR PUBLICATION Printed: September 18, 2007

instrument, has been described by Jagger,[1546] which he terms a " microsclerometer." It is supplied with a rigid standard and with apparatus for adjusting the instrument to the microscope ; also with rotating, lifting, and fixing adjustments, a balance beam with a rotatory diamond at one end, and a recording apparatus for the number of revolutions of the diamond and the depth of its penetration. It is capable of measuring variations of the rate, depth, or duration of the scratching, as well as of very accurately recording the weight above the diamond point. The opera-tions are watched under a low-power objective of the microscope. Almost all the varieties of modes of procedure which have from time to time been described may be followed with this instrument, involving abrasion, penetration, friction, and fracture.

## 14.5 Goniometers[1547]

**REWORK:** A goniometer is an instrument that either measures angles or allows an object to be rotated to a precise angular position. The term goniometry is derived from two Greek words, gonia, meaning angle and metron, meaning measure. In its most basic sense, a goniometer measures angles. Although specialized goniometers have been used in several fields (such as surveying, physics, and craniometry), the most common and historically significant goniometers were those used by mineralogists to measure the face angles of crystals.

The first goniometers were handheld instruments. Like the protractor on which they were based, these contact goniometers used two movable arms to directly measure angles. If the crystal were large and the faces smooth, it was easy to measure angles to within 1° or 2°. Under optimal conditions, the accuracy of this type of direct measurement might extend to 0.5°.

The first systematic use of a contact goniometer was by Jean-Baptiste Rome de l'lsle, whose Cnstallographie (1783) is considered the first scientific treatise on the subject. Using an instrument invented for the purpose and constructed by his assistant Carangeot, he made systematic measurements that established the invariability of the angles of certain simple forms of crystals.

Romé tried to establish crystallography as the basis of mineral identification. This approach to the study of minerals was influenced by his views on the nature of scientific inquiry. Rome supported the nomenclateurs (as their opponents called them), who agreed with Linnaeus in viewing classification to be one of the chief ends of the natural sciences. The systemateurs were more interested in building general systems on the basis of hypotheses that were not necessarily based on empirical research.

Rome's empirical approach stood in contrast to the work of Rene Just Haüy, who attempted to classify crystals according to a mathematical system that presumed the existence of basic "primitive forms" from which all crystals y/ete derived. A mathematical idealist, Haüy insisted on the principle of the "simplicity of nature," and stubbornly rejected any measurements that disagreed with the predictions of his theory. It is noteworthy that, even after more precise instruments were available, Haüy continued to use the less accurate contact goniometer.

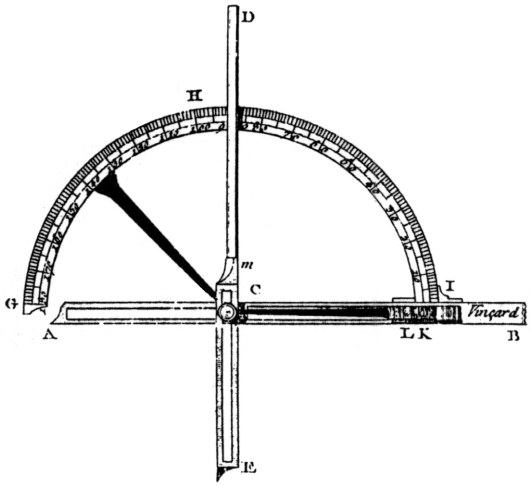
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### Carangeot's Contact Goniometer

These goniometers is the oldest of all well-known goniometers: it was invented in the year 1783 by Carangeot, by the same, which produced the Krystallmodelle from

[1546] Thomas Augustus Jaggar., " A microsclerometer, for determining thehardness of minerals," *American Journal of Science*, **4** (1897), p. 399-412.

[1547] Further historical information may be found in: A. Brezina, "Das neue Goniometer der K.K. Geologischen Reichsanstalt," *Jahrbuch der k.k. Geologische Reichsanstalt*, **34** (1884), p. 331-334. [p. 331-334, "Zusammenstellung der wichtigeren Publicationene über Goniometer und goniometrische Methoden in chronologischer Ordnung" (1772-1884, 67 articles listed).] • Ulrich Burchard., "History of the development of the crystallographic goniometer," *Mineralogical Record*, **29** (1998), no. 6, p. 517-577, 580-583, illus. • Steven C. Turner., "The reflecting goniometer," *Rittenhouse: Journal of the American Scientific Instrument Enterprise*, **27** (1993), p. 84-90. • Melvyn C. Usselman., "The reflective goniometer and its impact on chemical theory" (pp. 33-40) in: John Stock and Mary V. Orna., ed., *History and Preservation of Chemical Instrumentation.* Bost, Reidel, 1986.




Carangeot's Contact Goniometer (1783)

Thon for Rome de L'Isle. Regardless of its incompleteness, these goniometers through long time was the only instrument, which one needed for the measurement of the Krystalle. Since however all measurements of the famous Haüy with the Oarangeau schen " goniometers were implemented, so wiid it also sometimes the Haüy' goniometers mentioned.

The most important Theile of the Carangeot' goniometer, that on Fig. 545 in its natüi borrowed large ones is shown. are the following: a getheilter semicircle and two, rulers through-crossing in the center of the circle itself. Usually the semi-circle from brass and the rulers from steel are produced. The semi-circle must be in-GET-healed in 180 Theile or degrees, and. because of the small accuracy of that instruments supplied results, such is completely sufficient Einthei Eintheilung: but each degree is usually iretheilt still in two and even in three Theile. The rulers are mediate themselves on their mutual levels to a right-angled and in the center of the circle finding Axe connected, what shows the figure at the best one. One of these two rulers, i.e. off, always keeps the same direction, only it can. because of the cutouts in it, to be back and forth pushed: for the second ruler not only this movement is back and forth in a direction, but also a circulare movement possible. If thus the screw/is screwed in ". thus the two rulers remain fixed. in the opposite case both rulers are mobile in the directions mentioned above.

The use of the Carangeau' goniometer is completely simple, and one foresees the same already from its Construction. One has to thuen nothing more. as the two rulers on two Krvstallnächen. whose joint inclination one wants to measure to put on exactly and the number of the degrees, which one of these rulers on the GET-healed semi-circle giebt, to read off.

In order the Carangeot " sclien Goniometes obtains if possible satisfying results to received, must the following conditions be fulfilled:

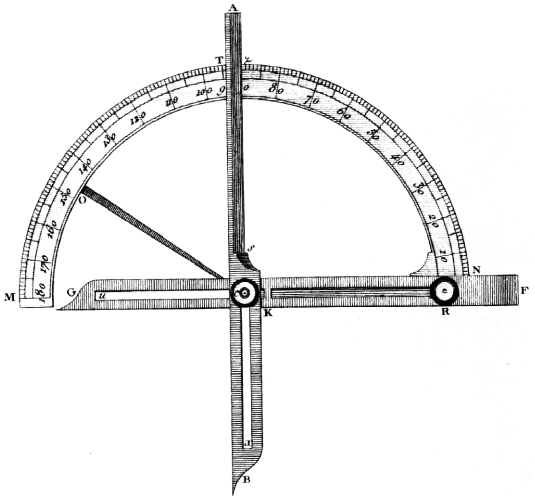
1. The level of the instrument must exactly right-angled on the edge or both surfaces, which forms the edge.
2. The rulers must with their edge curses exactly on the Krystallflächenanliegen. One reaches this best, by one the instrument and the Krystall against the light holds.

It verstheht itself automatically that the larger or smaller accuracy of the measurement with this instruments also on the large one and perfection of the Kn stable chosen to it " depends. Anyhow it is nearly not possibly mediates the Carangeau " schen goniometer exact Eesultaten to arrive too much: with all satisfying conditions and when numerous measurements, one can bring the error of observation of the Eesultats only up to degrees. Which concerns the errors of the individual observations, then the same exceed. two and even more degrees.

If the Kn stable on pieces the kind of mountain, which can be measured, grew up. so prevented often that freely or-, tehende end of the semi-circle the approximation of the rulers, in order to remedy this grievances, one cuts xlon semi-circle in the Theilpunkte 90° and fastens the second quadrant of the same to first averages a Charniers. so that it can be put back. For better arriving of the same goal used Brongniart at the measurement likewise rulers, as with Carangeau's the goniometers, only without semi-circle produced, and after only - call the measurement carried out and the rulers, mediate to a screw serving for it, were fixed, it put the same to read off on the GET-healed semi-circle around the number of the degrees.

In all cases, where no grosse accuracy is nöthig. where the Krystallflächen is not reflecting enough of the Krystalle are too large, and w o generally a Reflexionsgoniometer is unanwendbar is the Carangeau' goniometers a very useful instrument and can on grossem use be, because one becomes fast finished with it. These are the reasons from where it. regardless of all of his incompleteness, still up to our days steadily in the hands of the Mineralogen is.

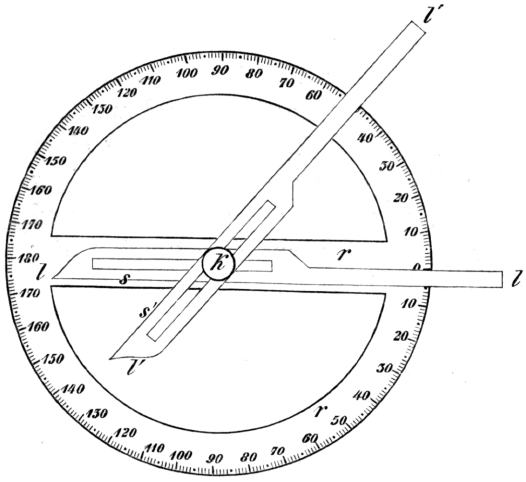
A goniometer for crystallography Goniometers are used in crystallography for measuring angles between crystal faces. They are also used in X-ray diffraction to rotate the samples. Other versions range from devices which measure human joint movement to ones which determine the angle of contact between a liquid droplet and a flat substrate.



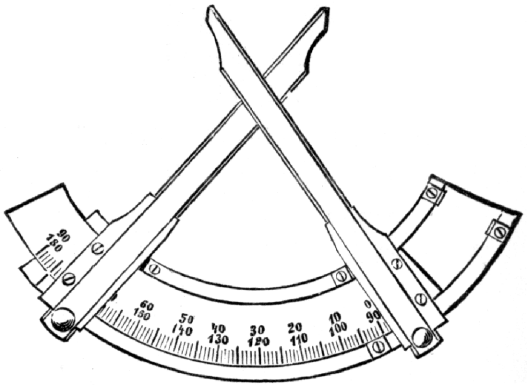
Haüy's Contact Goniometer (c1801)

In 1669 Nicolas Steno did observe the shapes of crystals precipitated from solution on a slip of glass and asserted that, for a given chemical salt, the shapes of the crystal faces formed may vary from crystal to crystal but not the interfacial angles. This is the first statement of the constancy of crystal angles more definitely proved a century later by Rome de l'Isle in 1783 and by Haüy in 1784 with the aid of the contact goniometer invented by Carangeot, assistant to Rome de l'Isle.

Viktor Goldschmidt designed a contact goniometer that used two circles.[1548] The purpose of this instrument is the measurement of large crystals or wood crystal models, and in particular the demonstration of the principles of the theodolite goniometeric methods for students.



Full Circle Contact Goniometer (c1905)



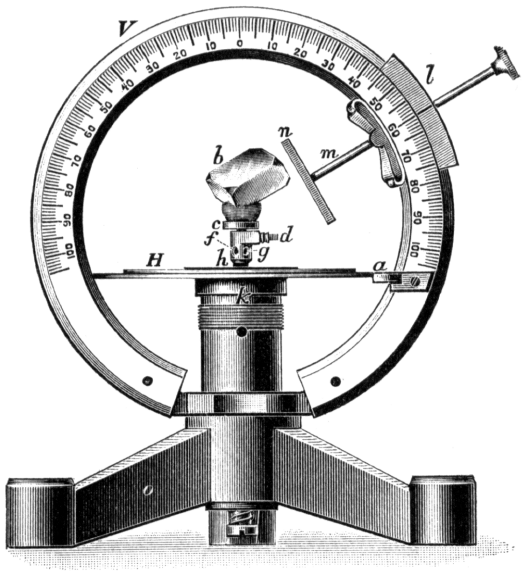
Quarter Circle Contact Goniometer

Other contact goniometers were designed.

## Reflecting Goniometer

In 1809, in an apparent attempt to refute Haüy's speculations, the English chemist William Hyde Wollaston invented the reflecting goniometer. Using the principle of the optical lever, Wollaston's simple and inexpensive instrument ingeniously solved the problems inherent in earlier goniometers. It consisted of a brass circle, graduated on its edge and

[1548] V. Goldschmidt., *Zeitschrift für Krystallographie*, **25** (18??), p. 321. • Leiss, *Die optischen Instrumente*, 1899, p. 137.




Goldschmidt's 2-Circle Contact Goniometer

mounted on one end of a horizontal axis. The crystal to be measured was mounted on the other end of the axis. The observer adjusted the crystal until a distant image was reflected off one of the facets into the observer's eye, rotated the crystal until the next surface reflected the same image (the eye being kept stationary), and then read the angle between the two crystal faces from the graduated circle. Wollaston's original instrument could measure the angle between two crystal faces to an accuracy of 5 minutes, and could measure crystals with faces as small as Vsoth of an inch.

Wollaston never actually named Haiiy in the article announcing his invention, but he characterized his work as "a result deduced from the supposed position ... of the surfaces, and from other seducing circumstances of apparent harmony by simple ratios." He also noted an error of over 30 minutes in Hauy's measurement of the calcium carbonate crystal, and predicted that his new instrument "will probably afford corrections to many former observations."

The reflecting goniometer is credited with separating mineralogy from chemistry as a discrete area of study. In his 1830 review of scientific progress, John Herschel characterized Wollaston's "elegant invention" as the prototype of a scientific instrument: "What an important influence may be exercised over the progress of a single branch of science by the invention of a ready and convenient mode of executing a definite measurement, and the construction and common introduction of an instrument adapted 'or it cannot be better exemplified than by the Mstance of the reflecting goniometer. This Sunple, cheap, and portable little instrument has changed the face of mineralogy, and given it all the characters of one of the exact sciences."

Although instruments nearly identical to Wollaston's original design continued to be used in classrooms throughout the nineteenth century, more precise versions were also introduced. The two most successful types were those developed by the French physicist Jacques Babinet in 1839, and by Eilherd Mitscherlich, professor of chemistry at the University of Berlin, in 1843. Babinet's reflecting goniometer had a horizontal graduated circle and was equipped with two telescopes, one serving as a collima-tor for the light source and the other for viewing the image. As Babinet was noted for his work with diffraction gratings, it is not surprising that his goniometer proved to be particularly well suited to spectroscopic investigations. In their 1890 Catalogue, the Societe Genevoise described their Babinet goniometer as an instrument that "may be used without modification as a spectrometer" (see spectrophotometer).

This is an instrument of far greater precision, and is always used for the accurate measurement of the angles when small crystals with bright faces are available. As a rul© the smaller the crystal the more even are its faces, and when these are smooth and bright they reflect sharply denned images of a bright object; By turning the crystal about an axis parallel to the edge between two faces, the image reflected from a second face may be brought into the same position as that formerly occupied by the image reflected from the first face; the angle through which the crystal has been rotated, as determined by a graduated circle to which the crystal is fixed, is the angle between the normals to the two faces.

Several forms of instruments depending on. this principle have been devised, the

earliest being the vertical-circle goniometer of W. H. Wollaston, made in 1800. This consists of a circle m, graduated to degrees of arc and reading with the vernier h to minutes, which turns with the milled head t about a horizontal axis., The crystal is attached with wax (a mixture of beeswax and pitch) to the holder.. q, and by means of the pivoted arcs it may be adjusted so that the edge between two faces (a zone-axis) is parallel to, and coincident with, the axis of the instrument. The crystal-holder and adjustment* area, together with the milled head 5, are carried on an axis which passes through the hollow axis of the graduated circle, and may thus be rotated independently of the circle. In use, the goniometer is laced directly opposite to a window, with its axis parallel to theorizontal window-bars, and as far distant as possible. The eye isplaced quite close to the crystal, and the image of an upper window-bar (or better still a slit in a dark screen), as seen in the crystal-faceis made to coincide with a lower window-bar (or chalk mark on thefloor) as seen directly: this is done by turning the milled head J",the reading of the graduated circle having previously been observedWithout moving the eye, the milled head t, together with the crystal,is then rotated until the image from a second face is brought into thesame position; the difference between the first and, second readingsof the graduated circle will then give the angle between the normalsof the two faces.

Several improvements have been made on Wollaston's goniometer.. The adjustment-arcs have been modified; a mirror of black glass fixed to the stand beneath the crystal gives a reflected image of the signal, with which the reflection from the crystal can be more conveniently made to coincide a telescope provided with cross-wires in ves greater precision to the direction of the reflected rays of light; and with the telescopea collimator has sometimes been used.

A still greater improvement was. effected by placing the graduated circle: in a horizontal position* as in the instru-ments of, E. L. Malus (1810), F. C. von Riese (1849) and JJ Babinet (1839), Many forttisj* the *horizontal-circle goniometer* have, been constructed r they *** provided with a telescope and collimator, and in construction at* essentially the same as a spectrometer, with the addition of arrange ments for adjusting and centring the crystal. The instrument: shb* in fig. 3 is made by R. Fuess of Berlin. It has four concentric axes, which enable the crystal-holder A, together with the adjustrteiwj arcs B and centring-slides D, to be raised or lowered, or to be rota**" independently of the circle H; further, either the crystal-holder o the telescope T may be rotated with the circle, while the otn remains fixed. The crystal is placed on the holder and adjustedo that the edge (zone-axis) between two faces is coincident with theaxis of the instrument, light from an incandescent gas-burnerpasses through the slit of the collimator C, and the image of the slit/signal) reflected from the crystal face is viewed in the telescope.The damp a. and slow-motion screw F enable the image to be.brought exactly on the cross-wires of the telescope, and the positionp the circle with respect to the vernier is read through the lens.The crystal and the circle are then rotated together until the imagefrom a second face is brought oh the'cross-wires of the telescope, andhe angle through which they have been turned is the angle betweenthe normals to the two faces. While measuring the angles betweenthe faces of crystals the telescope remains fixedly the clamp (3, but'when this is released the instrument may be used as à spectrometerTor refractometer for determining; by the method of minimumdeviation, thé indices of refraction of-an artificially cut prism or of atransparent crystal when the faces are suitably inclined to, oneanother.

With,a one-circle goniometer, such as is described above, it is necessary to mount and re-adjusi the crystal afresh for thé measurement of each me of faces (i.e. each set of faces intersecting in parallel edges); with very email crystals this operation takes a considerable ,time, and the minute faces are not readily identified again. Further, Jn certain cases, it is not possible to measure thé angles between zones, nor to determine the position of small faces which do not lie in prominent zones on the crystal. These difficulties have been overcome by the use of a two-circle goniometer



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or. theodolite-goniometer, ¿ which as a combination of a vertical-circle goniometer and one with a : horizontal-circle was first employed by W. H. Miller in 1874. Special forms have been designed by E. S. Fedorov (1889), V. Goldscnmidt (1893) S. Czapski (1603) and F. Stoeber (1898), which differ mainly jn the arrangement of the optical parts. In these instruments the crystal is set up and adjusted once for all, with the axis of a prominent zone parallel to the axis of either thé horizontal or the vertical 'circle. As a rule, only in this zone can the angles between the faces be measured directly; the positions of all the other faces, which need be observed only once, are fixed-by the simultaneous readings of the two circles. These readings, corresponding to the polar distance and 'azimuth, or latitude and longitude readings of astronomical telescopes, must be plotted on a projection before the symmetry Of the crystal is apparent; and laborious calculations are necessary in order to-determine the indices of the faces and the angles between them, and the other constants of the crystal, or to test whether any three faces are accurately in a zone.

These disadvantages are overcome by adding still another graduated circle to the instrument, with its axis perpendicular to the axis of the vertical circle, thus forming a three-circle goniometer. With such an instrument measurements may be made in any zone or between any two faces without re-ad justing the crystal; further the .troublesome calculations are avoided, and, indeed, the instrument may be used for solving spherical triangles. Different forms of three-circle goniometers have been designed by G. F. H. Smith (1899 and 1904), E. S. Fedorov (1900) and J. F. C. Klein (1900). Besides being used as a one-, two-, or three-circle goniometer, for the measurement of the interfacial angles of crystals, and as a re-fractometer for determining refractive indices by the prismatic method or by total reflection, Klein *6 instrument, which is called a polymeter, is fitted with accessory optical apparatus which enables it to be used for examining a crystal m parallel or convergent polarized light and for measuring the optic axial angle.

Goniometers of special construction have been devised for certain purposes; for instance, the inverted horizontal-circle goniometer of H. A. Miers (1903) for measuring crystals during their growth in the mother-liquid. A. E. Tutton (1894) has combined agoniometer with lapidaries appliances for cutting section-plates and prisms from crystals accurately in any desired direction. The instrument commonly employed for measuring the optic axial angle of biaxial crystals is really a combination of a goniometer with a polariscope. For the optical investigation of minute crystals under the microscope, various forms of stage-goniometer with one, two or three graduated circles have been constructed. An ordinary microscope fitted with cross-wires and a rotating graduated stage serves the purpose of a goniometer for measuring the plane angles of a crystal face or section, Deing the same in principle as the contact goniometer.

For fuller descriptions of goniometers reference may be made to the text-books of Crystallography and Mineralogy, especially to P. H. Groth, *Physikalische Krystauographie* (4th ed, Leipzig, 1905). See also C Leiss, *Die optischen Instrumente der Firma R. Fuess, deren Jieschreibungi Justierung uni Anwendung* (Leipzig, 1899).

Mineralogists found the Babinet goniometer advantageous when measuring large crystals or those attached to a large piece of rock. Physicists saw it as one of the most valuable instruments in the laboratory. In the goniometer form it could be used to measure the angles of crystals, find the index of refraction of solids or liquids, and study dispersion. In the spectrometer form, it could be used to measure wavelengths. Edward C. Pickering, who developed the first college physics laboratories in the United States, recommended that each laboratory acquire "one large and very accurate" Babinet goniometer and "others of smaller size for work requiring less precision."

Mitscherlich's basic design had a vertical graduated circle and two telescopes. The measurement was made when the illuminated reflection of the cross hairs in the first telescope were made to coincide with those in the viewing telescope on successive crystal faces.



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Over the years, instrument-makers produced a wide variety of Mitscherlich-type goniometers of increasing complexity. Although offering extreme precision, these elaborate instruments required patience and skill to operate properly.

Although the optical goniometer was largely replaced by other types of measurement in the early twentieth century, it continues to have limited applications in mineral identification.

The contact goniometer was followed in 1809 by the single-circle reflecting goniometer of Wollaston. With its introduction precision measurement of crystal angles began and engaged the attention of crystallographers in Europe. In 1874 Miller constructed a two-circle goniometer by adding a vertical circle to the usual horizontal circle instrument; this arrangement was modified by Fedorov in 1889 who used an autocollimating telescope in place of the collimator and telescope. In 1893 three two-circle goniometers were described, one by Fedorov, the second by Czapski, and the third by Victor Goldschmidt. Of these the design by Goldschmidt has proved to be the best and is now widely used and has been of the greatest aid to crystallography. In 1889 and 1904 G. F. Herbert Smith described two models of a three-circle goniometer. Impressed by the usefulness of the measurement of crystal faces in a zone, he employed the third circle to aid in the setting of a crystal so that the angles in any one of its zones can be measured directly on the horizontal circle. The three-circle goniometer was also used for the solution of spherical triangles. Although the three-circle goniometer is interesting and serves its purpose well, it has not been adopted as a tool by mineralogists.

Malus designed a reflective goniometer that he published about.[1549]

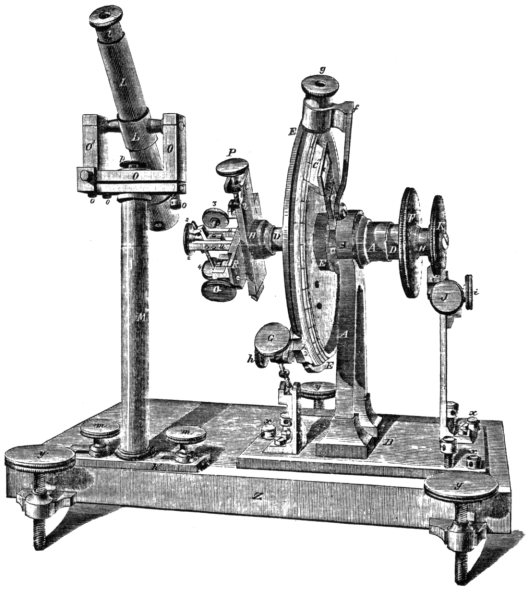
Crystal goniometers have served for purposes other than the measurement of angles. In 1889 V. Goldschmidt described a cutting goniometer for making models of actual crystals. In 1894 Tutton exhibited his single-circle crystal-grinding goniometer which he used later in preparation of the crystal plates and prisms for his extended investigations into the isomorphous series of the orthorhombic sulphates and selenates of potassium, rubidium, and cesium, and into other isomorphous series. In 1915 F. E. Wright described a two-circle crystal-grinding goniometer for grinding faces of any desired orientation on a crystal and accurate in position to one-half minute of arc. Orientated faces on crystals of quartz, calcite, and other minerals were ground with the aid of this apparatus and used in the measurement of the changes of crystal angles with changes of temperature. For the measurement of crystal angles at elevated temperatures a special electric resistance furnace, water-cooled on the outside and mounted on the horizontal plate of the Goldschmidt goniometer was constructed and measurements were made to temperatures of 1250° C. For measurements at low temperatures V. M. Goldschmidt constructed a special apparatus for surrounding the mounted crystal with an atmosphere approaching in temperature that of solid carbon dioxide, or of liquid air.

The equipment at present available for the measurement of crystal angles is satisfactory and adequate for crystals of appreciable size; but there is still room for improvement in the measurement of minute crystals and of small crystal faces only one-tenth millimeter in width. The amount of light reflected from such faces is so small that the reflection signals are weak and spread out as a result of diffraction. At present the best procedure appears to be the use of an intense carbon arc lamp as a source of illumination together with a telescope having an objective lens of short focal length and nice adjustment of the entire optical system. The best results will be obtained with a goniometer of special design.

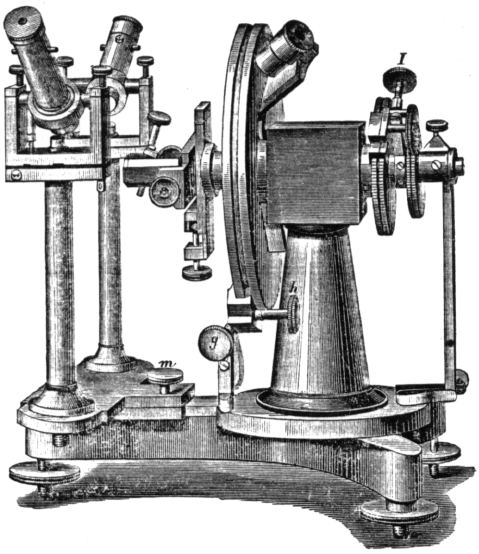
Instrument design. In this connection it is well to state that each instrument intended for precision work should be designed with reference both to purpose and rugged mechanical performance and to adjustment facilities, so that the observer will be in a position at any time to test the accuracy of adjustment of all parts of the instrument by

[1549] Malus and Cauchoix., *Gilbert's Annalen*, **37** (1811), p. 388-389. • Malus., "Description et usage d'un gonioètre répétiteur," *Arcueuil. Mém. de Phys.*, **3** (1817), p. 122-131.

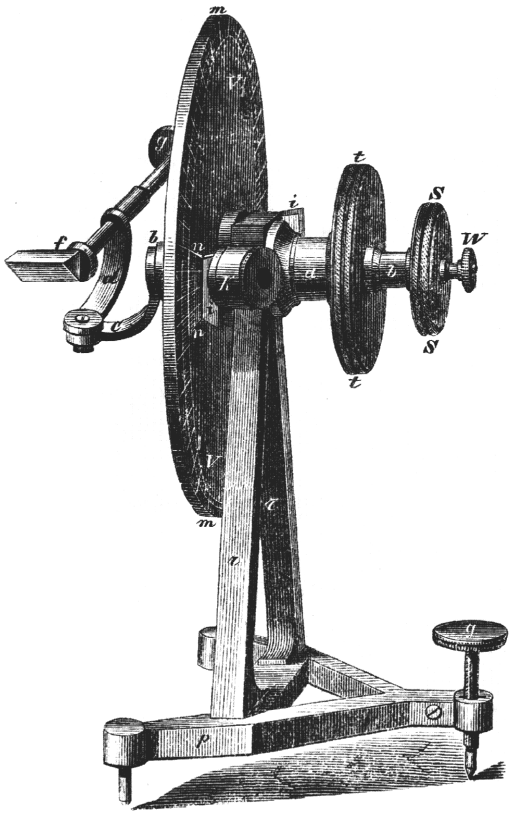
an orderly procedure of successive adjustments so arranged that no later adjustment disturbs preceding adjustments. If this precaution is not taken, the observer is forced either to devise a makeshift method of adjustment, which is never satisfactory, or to place implicit faith in the skill of the manufacturer to furnish the instrument in correct adjustment and to rely upon maintenance of the adjustment in spite of the jars and jolts of transportation and the inevitable slight movements upon aging of the metals of which the instruments are made. Another result of long and sometimes bitter experience is the futility of the so-called universal instruments of a generation ago. Instruments of this type are likely to be unwieldy and of relatively poor design, so that they are not satisfactory for any one of the several kinds of measurement for which they are intended.



Mitscherlich Goniometer (c1843)



Mitscherlich Goniometer (c1854)



Reflecting Goniometer (c1865)

**Mitscherlich's Goniometer**[1550]

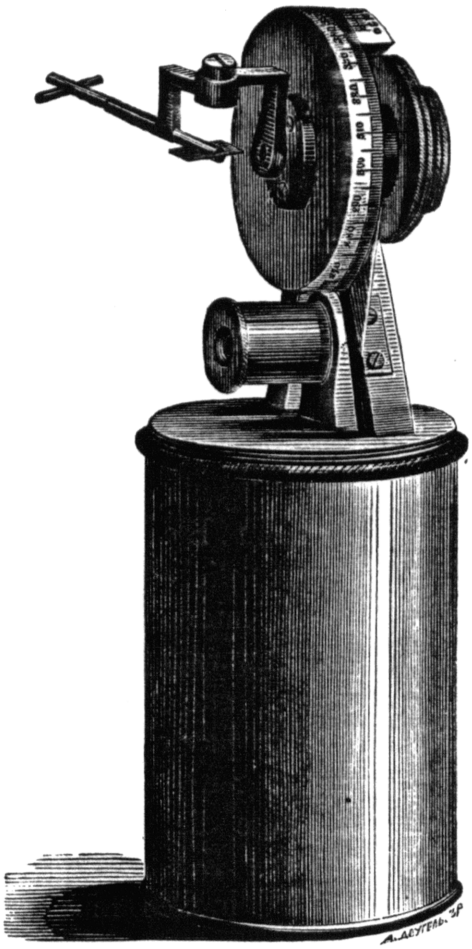
This instrument belongs, by its Construction, comfort to the use and sharpness of the results supplied by it, to which are most beautiful its kind and. before-to-resembled spread in this last time, very much. It is to be only bedauren. that. by entangling the Construction of the individual Theile. the

[1550] E. Mitscherlich., "Ueber einen Goniometer," *Abhandlungen der Berlinische Akademie der Wissenschaften*, 1843.

instrument is so importantly more theuer. Generally it is to be used rathsam this instrument only in such cases, where one has with the most perfect Krystallen too thun and where one purifies ¡ranz observations to employ wants. otherwise usual volume reading clay/tone " is completely sufficient the sche instrument. The hit scherlich'bche instrument is not anything different. aluminium in many relations inheritance ores Wollaston' goniometers, and it is characterised before-to-resembled by the mechanism. which in addition serves around the edge line well for centriren and over the eye a certain position to give.

In the Mitscherlich' goniometer the circle GET-healed EE very finely, so that the Xonius this Theilung up to 1 (J Secunden to read off permitted. Generally, with the fulfilment of the most substantial conditions, one can reduce the error, which is due to the attitude of the instrument, up to minute. The Fig. the instrument represents 548 in such a way, like it by its harvesting Indian was originally described.

A Reflexionssroniometer is for the traveler Mineralogen one books useful thing and rewiss in fell cases it important services to carry out can. Unterbeut the same however no Yei änderunc in its outside form, then receives the traveler very uncomfortable luggage, which makes itself perceptible at most in the countries, where the Wesrevei does not bindurnren yet is manufactured. In order to heal this evil, Mitscherlich manufactured goniometers. on journeys the transport bay is easy. This instrument is nothing else, as the Wollaston' goniometers, but only on of smaller dimension and such mechanism that the germinating it without the smallest Schwitzigkeit. like every different one gewflhn gewflhn-hchen (article, to treat can (Fig. 55 (1). The GET-healed circle of the same has 2 tariff in the diameter, and its onius ciebt the AYinkel up to 4 minutes on. The canze instrument can into a messingenen Cylinder put and then free standing anüeschroben to become. With the use it becomes A on the hollow (can serve more.Minder abgeschroben and C more linder then than Piedestal, as this is to be seen 550 on Fic.



Mitscherlich's Travel Goniometer

The Reflexionsgoniometer of penalty differs on the Wollaston' goniometer wesentlichst by the fact that its getheilter circle horizontal posed, and that to the same still another telescope is added. With the application of this instrument, one places the edge, in the center of the GET-healed circle, which can be measured, vertically. As article here a vertical Object (e.g. the edge of a house or somewhat a like) serves, from which the coming reflec reflec-tirten and from the Krystallflächen jets, by a telescope are caught. de " en Axe of the level of the GET-healed circle are parallel and exactly toward the center of the same directed. and its vertical thread is brought with the picture whether-Objects to the Goincidenz. Otherwise the Princip of the measurement is whole the same, as with the Wollaston' goniometer.

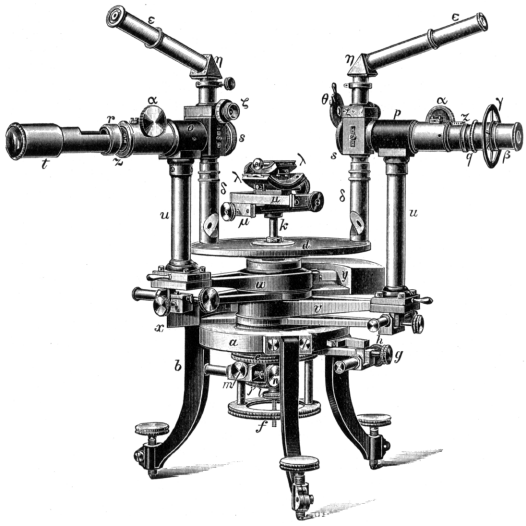


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The Babinet' goniometer is again nothing else as the Malus' goniometer, which has two horizontal telescopes instead of a telescope. The hair cross of this second horizontal telescope serves here as a unendlich'entfern unendlich'entfernter article.

Crystal goniometers have served for purposes other than the measurement of angles. In 1889 V. Goldschmidt described a cutting goniometer for making models of actual crystals. In 1894 Tutton exhibited his single-circle crystal-grinding goniometer which he used later in preparation of the crystal plates and prisms for his extended investigations into the isomorphous series of the orthorhombic sulphates and selenates of potassium, rubidium, and cesium, and into other isomorphous series. In 1915 F. E. Wright described a two-circle crystal-grinding goniometer for grinding faces of any desired orientation on a crystal and accurate in position to one-half minute of arc. Orientated faces on crystals of quartz, calcite, and other minerals were ground with the aid of this apparatus and used in the measurement of the changes of crystal angles with changes of temperature. For the measurement of crystal angles at elevated temperatures a special electric resistance furnace, water-cooled on the outside and mounted on the horizontal plate of the Goldschmidt goniometer was constructed and measurements were made to temperatures of 1250° C. For measurements at low temperatures V. M. Goldschmidt constructed a special apparatus for surrounding the mounted crystal with an atmosphere approaching in temperature that of solid carbon dioxide, or of liquid air.

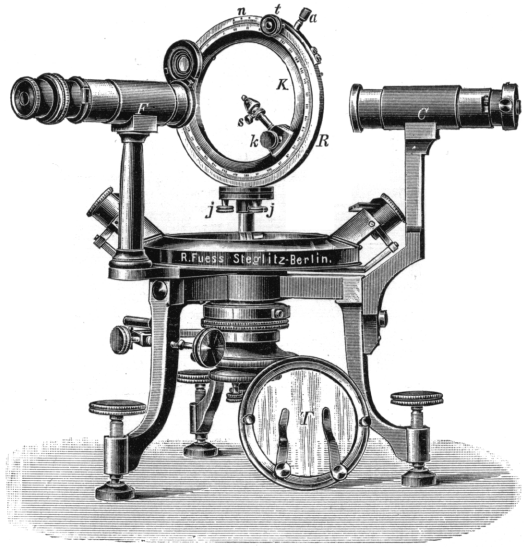
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Fuess Goniometer, Model 1a (c1911)

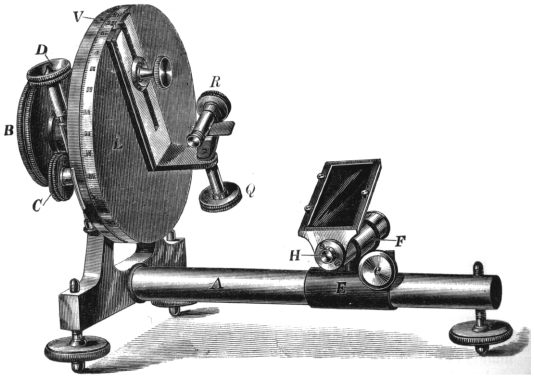
an objective lens of short focal length and nice adjustment of the entire optical system. The best results will be obtained with a goniometer of special design.

In 1874, William H. Miller of Cambridge constructed a two-circle goniometer by adding a vertical circle to the usual horizontal circle instrument.[1551]




Fuess Goniometer, after Herbert Smith (c1911)

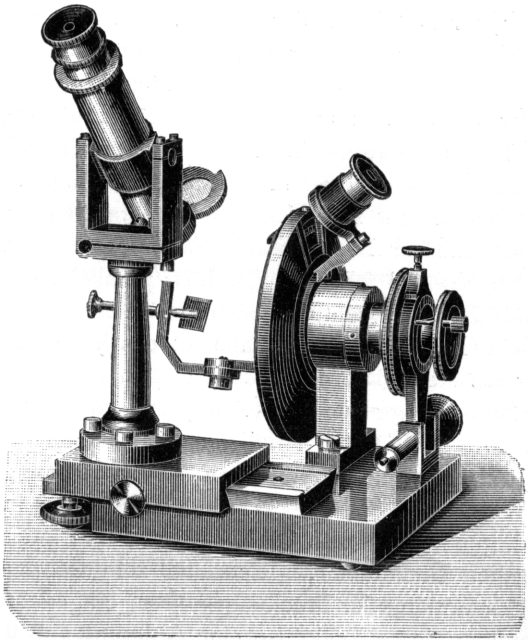
[1551] W.H. Miller., "On a new form of the Reflective Goniometer," *Philosophical Magazine*, series 2, **5** (1876), p. 281-285.; noticed in *Zeitschrift für Krystallographie*, (1877), p. 66.




Miers Student Goniometer, 1891

The Miers Student's Goniometer.—This is a much less costly form of goniometer constructed on the vertical-circle principle by Messrs. Troughton and Simms to the designs of Sir Henry Miers, and is eminently suited for the use of students. The observation by telescope and collimator is replaced, in the simple form of the instrument recommended, by the use of a mirror to reflect the image of a distant signal-slit, placed in an otherwise darkened window, and which is likewise caused to be simultaneously reflected from the crystal face, the reading of the circle being taken when the two reflections are brought into coincidence to an observer looking vertically downwards on to crystal and mirror from above. A general view of the instrument is given will assist in explaining its principle.

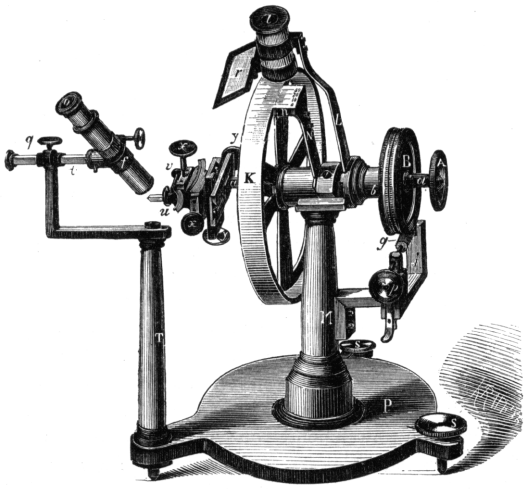
A similar instrument with an equally accurate circle but with a simpler crystal-adjusting apparatus of the type originally used by Wollaston, the inventor in the year 1809 of the reflecting goniometer, is also constructed by Messrs. Troughton and Simms at a considerably lower cost, and is shown in Fig. 29. The construction of the two simple adjusting movements d' will be quite clear from the illustration; two rods u and v at right angles to each other, one of them, v, carrying the crystal-holder x, can be rotated in bearings by milled heads y and z, and serve for the adjustment of the crystal edge, that is, of the pair of faces intersecting in the edge. The centring is achieved by means of the slotted bar e', which is capable of being clamped to the circle when the crvstal is centred, by the milled head a shown in the figure, and which carries the adjusting movements at the end of an elbow f3 springing from its inner end. In using either form of this goniometer the observer looks down from above on to the crystal and mirror, but with the eye accommodated for distance, so as to focus sharply the images of the window slit reflected from the crystal face under observation and from the emirror. In order to adjust the crystal so that the two images exactly coincide, it is convenient to cut off half of the light falling on the oirror from the signal-slit, by means of a little cardboard screen placed in the table in front of the goniometer, of the right height to perform this function while allowing the light to fall freely on the crystal. By moving the screen about over the table, part or all of the signal reflection m the mirror can be cut off, so as to distinguish it plainly from the crystal reflection, and when half only is cut off it is easy to make the signal-image from the crystal form an exact prolongation of the remain-g half, and in this way obtain a better coincidence than by complete verlapping, as it is difficult to distinguish the separate edges when near incidence. When this coincidence has been thus attained the reading [f the circle is taken.



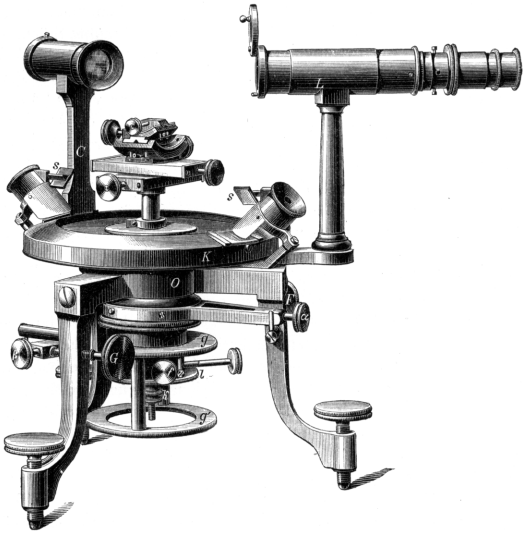
Klein Goniometer, 1905



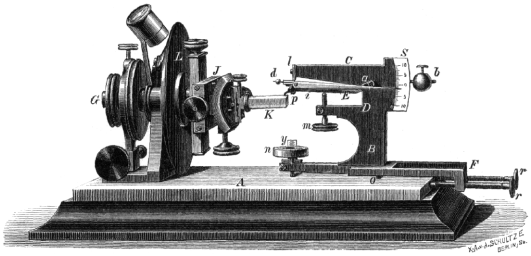
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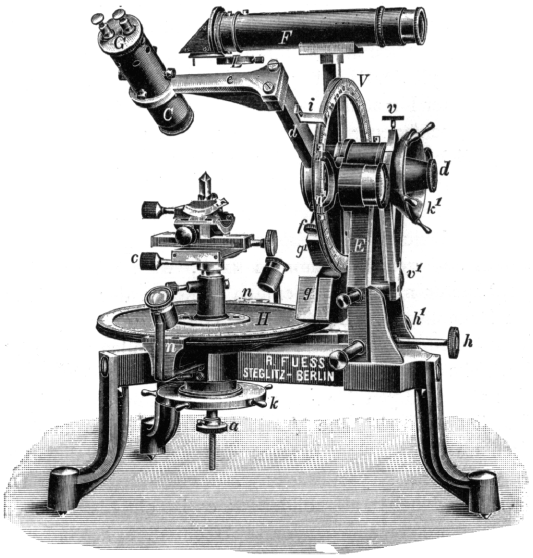
Bohm and Widemann Goniometer, c1905



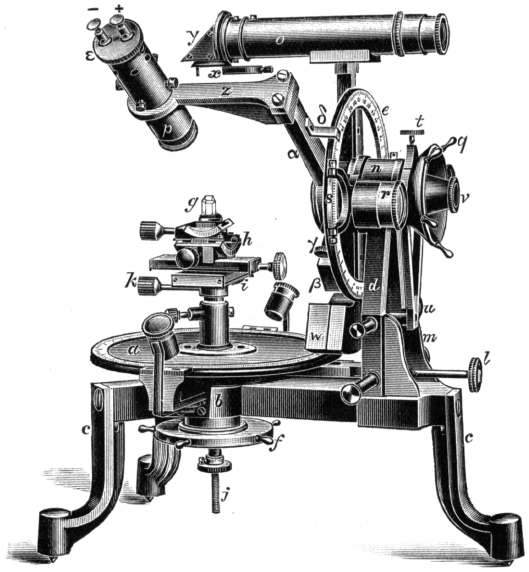
Websky Goniometer, c1905



Fühlhebel Goniometer, c1905




Wulff Goniometer, c1905



Czapski Goniometer, c1911

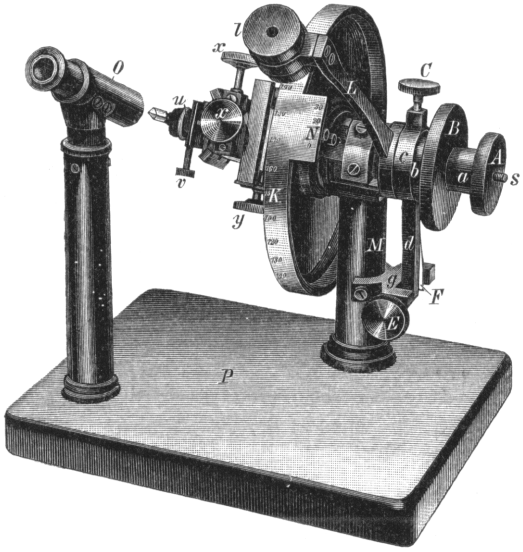
Goldschmidt modified a two circle goniometer so that it could be used to grind angles.[1552]

Goldschmidt proposed a two circle goniometer.[1553]

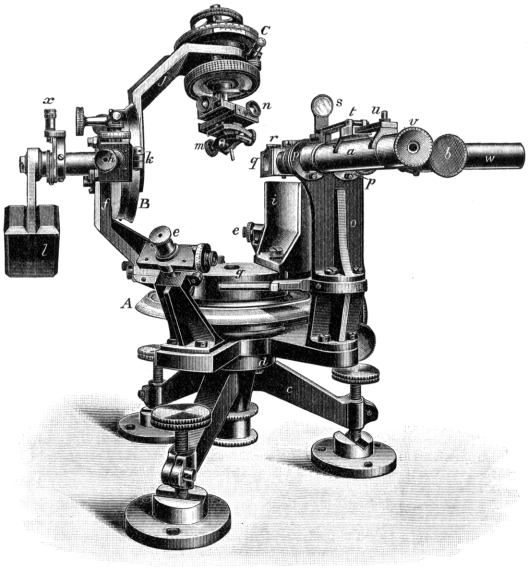
The instrument manufacturing firm of Troughton and Simms introduced a goniometer with a horizontal circle. Its principle of

[1552] Goldschmidt., "???," *Zeitschrift für Krystallographie*, **51** (1912), p. 359-??.

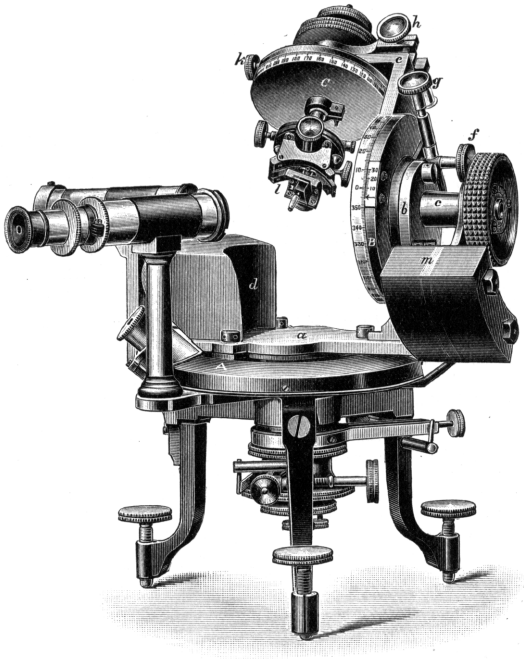
[1553] Goldschmidt., "???," *Zeitschrift für Krystallographie*, **29** (1898), p. 333-??.



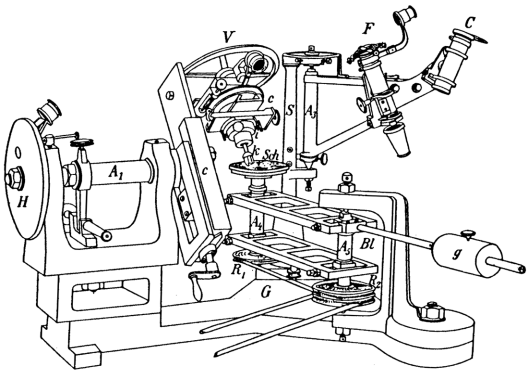
Goniometer, c1905



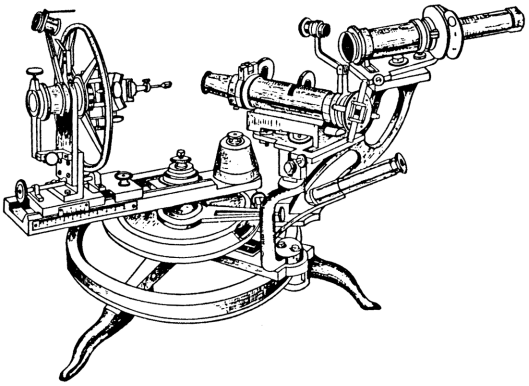
Herbert Smith Three Circle Goniometer, c1911



Herbert Smith Goniometer First Form, c1905



Goldschmidt's Grinding Goniometer, 1912



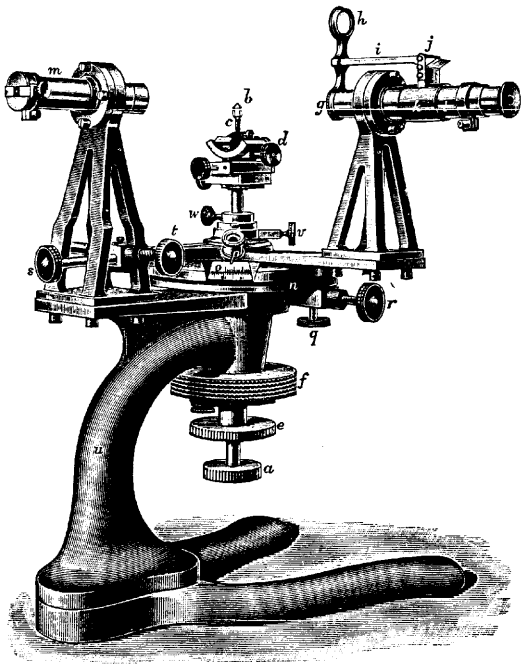
Goldschmidt Two Circle Goniometer, 1898

operation is the same as the Fuess insturments.

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ENCYCLOPEDIA BRITANNICA (1911)

Goniometer (from Gr. yoivia, angle, and pArpov, measure), an instrument for measuring the angles of crystals; there are two kinds—the contact goniometei- and the reflecting goniometer, Nicolaus Stena in 1669 determined the interfacial angles of quartz crystals, by cutting sections perpendicular to the edges, the plane angles of the sections




Troughton and Simms Horizontal Circle, c1911

being then the angles between the faces which are perpendicular to the sections. The earliest instrur ment was the contact goniometer devised by Carangeot in 1783. *The Contact Goniometer* (or *Hand-Goniometer*).—This consist of two metal rules pivoted together at the centre of a graduated semicircle (fig. 1). The instrument is placed, with its plane perpendicular to an edge betweentwo faces of thecrystal to be measured, and the rulesare brought intocontact with thefaces; this is bestdone by holding the crystal up against the Kght with theedge, in the line ofsight. The anglebetween the rules,as read on thegraduated semicircle, ; then givesthe ingle betweenthe two faces. The rules are slotted so that they may be shortened and their tips applied to a crystal partly embedded in its matrix. The instrument represented in fig. 1 is practically the same in all its details as that made for Carangeot, and it is employed at the present day for the approximate measurement of large crystals with dull and rough faces. S. L. Penfield (1900) has devised some cheap and simple forms of contact goniometer, consisting of jointed.arms and protractors made of cardboard or celluloid.

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The original reflection goniometer is that of Wollaston.[1554] In this a base and column support in a collar a hollow axle to which there is attached at one end a vertical disc with a graduated rim and at the other end a handle. Through this axle passes a second axle, with at one end the crystal holder and at the other a handle. These two axles may be clamped to turn together, or, by the inner axle, the crystal may be rotated without the graduated circle.

In the simplest forms of this goniometer the crystal is fastened with wax to a thin, flexible, brass plate, and this is fixed in a holder which has several simple motions by means of which the faces of the zone to be measured can be made to project clear of the apparatus and the edge to coincide with the axis of rotation. The signal may be a horizontal window bar twenty to thirty feet away, or better, a horizontal slit in a screen before an artificial light and it must be parallel to the axis of rotation. The eye is brought almost into contact with the crystal and there watches for the reflection of the signal as the faces successively move into position.

To secure a constant line of sight a reference mark may be made below the crystal parallel to the signal, or better, a second image of the signal may be obtained in a small mirror, the plane of which is parallel to the axis of rotation, or still better, a telescope with cross hairs may be used. In each case the rotation is continued until the image of the signal is bisected by or coincides with the reference mark.

Mallard's[1555] modification of the Wollaston goniometer, shown in Fig. 191 on the left, differs from the earlier types in the sub-stitution of a better crystal holder; the crystal is supported in the manner suggested by Groth that is, it is fixed with wax on a small circular disc, d, and, by turning the screws v, v, and v', v', can receive two movements of rotation, on two arcs of circles perpendicular to each other which have thei o common center

[1554] W.H. Wollaston., "Description of a reflective goniometer," *Philosophical Transactions of the Royal Society of London*, 1809, p. 253-259.

[1555] Er. Mallard., "???," *Annales des Mines*, **??** (1887), Nov-Dec.

near the middle of the crystal, A, so that the changes of orientation of the crystal do not too much displace its center of gravity. [**Moses, *Character of Crystals*, 1899, has illustration of Mallard's Goniometer**]

For the proper centering, the entire system which holds the crystal is attached to two sliding planes, g and g', which, by means of the screws, u and ur, impart to the crystal two movements of translation in a plane perpendicular to the axis of rotation. There is also a tangent screv for fine rotation and the mirror, M, has four motions of adjustment parallel to the axis of rotation. Any signal may be used, but preferably the collimator and artificial light, as shown in the figure.

The collimator is a cylinder, C, with at one end a large lens, L, and at the other, which is the exact focal plane of the lens, an adjustable plate, Fig. 192, pierced with signals, f, f',f", of various forms beneath each of which is a fine reference slit. The light from an Argand gas lamp, R, or a Welsbach burner passes through the central signals, emerges as parallel rays from the lens and is reflected to the eye at the same time from the crystal face and the mirror.

A greater degree of accuracy would be secured by the addition of an observation telescope, as in the Mitscherlich* modification of the Wollaston, but this is accompanied by loss of light and usually makes a dark room necessary, whereas the Mallard-Wollaston gives good results in ordinary light.

Professor Groth describes a simple, inexpensive Wollaston with a telescope fixed parallel to the plane of the graduated circle and centered on the goniometer axis. The crystal holder is like that of the Mallard instrument, but the inner axle, which ordw.a'ily rotates the crystal independently, is replaced by a screw which moves the crystal horizontally in the direction of the axis The signal used by Professor Groth is a very small incandescent lig.ht at a distance of about thirty feet where it appears like a luminous point.

The principal objection to the VVollaston type of goniometer is that the weight of the crystal tends to throw it out of adjustment.

Babinet, v. Lang, Miller, Websky and others have gradually developed this more perfect and more generally applicable variety of goniometer, and there is little doubt that for simplicity of adjust-ments and perfection of construction the instrument known as the Fuess Model II. at present excels all others.

### Theodolite or Two-Circle Goniometers

In the reflection goniometeis described all faces of the zone which is placed perpendicular to the graduated circle reflect the signai and it the circle is considered to be the plane of projection their poles are in the circumference at angles apart equal to those meas-uring the rotation.

If a second direction of rotation at right angles to the other be added, any face in any zone inry be referred to this first zone by the two motions necessary to bring it into the field, the one giving the point where its meridian cuts the primitive circle, the other giving the number of degrees on this meridian from the primitive circle. Czapski, Goldschmidt and v. Federov have described such instruments that of the latter, shown in Fig. 197, consists of a telescope B, which is also the collimator. The signals are on the revolving disc b, and the light entering at the focal plane of the objective passes through a snail total reflecting prism and emerges as parallel rays. There is an sxtralens to bring the crystal into focus or, by means of the spring clamp h and the rack and pinion H and K, one of the weaker objectives of a microscope may "be focussed on the crystal. The eye-piece has an adj istable irisblende.

The stand consists of a tripod with a bored conical head in which rests the graduated circle C turned by d and read by the fixed vernier N, using clamp e and tangent screw. The stand also sup-ports D, the carrier of the vertical circle, which can be clamped to the stative by g, or to the horizontal circle by e.

The vertical circle is a complete Wollaston goniometer, but rotates with the horizontal circle when e is clamped. By transferring the centering apparatus to the horizontal circle the instru-ment may be used as a goniometer with verticil axis.

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## 14.6 Optical Instruments[1556]

Light and other forms of electro-magnetic radiation interact with physical objects. The behavior is different for each substance, and in the case of mineralogy, studying the interaction has played a significant role in furthering the science. In particular the investigation of light rays as it transverses transparent crystals led to the development of many new types of instruments. An optical instrument either processes light waves to enhance an image for viewing, or analyzes light waves (or photons) to determine one of a number of characteristic properties.

### 14.6.1 Microscopes[1557]

**REWORK:** A microscope (Greek: ????? (micron) = small + ????? (skopein) = to look at) is an instrument for viewing objects that are too small to be seen by the naked or unaided eye. The science of investigating small objects using such an instrument is called microscopy, and the term microscopic means minute or very small, not easily visible with the unaided eye. In other words, requiring a microscope to examine.

[1556] Further historical information may be found in: Siegfried Czapski and Otto Eppenstein., *Grundzüge der theorie der optischen instrumente nach Abbe*. 3. Auflage. Leipzig, J. A. Barth, 1924. xx, 747 p., illus. • C. Leiss., *Die optischen Instrumente der Firma R. Fuess*. Deren Beschreibung, Justierung and Anwendung. Leipzig, 1899. 397 p., 233 illus. • Moritz von Rohr., *Die optischen Instrumente*. Leipzig, B.G. Teubner, 1906. v, 130 p., 84 illus. [Descriptions of various optical instruments.] • G.L. Turner., "The history of optical instruments. A brief survey of sources and modern studies," *History of Science*, **8** (1969), p. 53-93, illus

[1557] Further historical information may be found in: Alfred N. Disney, et al, ed., *Origin and development of the microscope, as illustrated by catalogues of the instruments and accesories, in the collections of the Royal Microscopial Society*. Together with bibliographies of original authorities, 30 plates and 36 text-figures ... preceded by an historical survey on the early progress of optical science by the editor. London, The Royal Microscopial Society, 1928. xi, [1], 303, [1] p., illus., 30 plates (including facsims.), illus. • H. Freund and A. Berg., *Geschichte der Mikroskopie. Leben und Werk grosser Forscher*. Frankfurt-am-Main, Umschau Verlag, 1966. 3 vols. xv, 378 p.; xv, 506 p., xvi, 550 p., 143 plates. [Published as: *III. Angewandte Naturwissenschaften und Technik*. A comprehensive history of the microscope and its greatest researchers through biographical portraits.] • Vasco Ronchi., "New history of the optical microscope," *Indian Journal for the History of Science*, **1** (19??), p. 46-??.

The most common type of microscope–and the first to be invented–is the optical microscope. This is an optical instrument containing one or more lenses that produce an enlarged image of an object placed in the focal plane of the lens(es). There are, however, many other microscope designs.

It is not known where, or by whom, the microscope was invented. When it was invented is clearer; almost certainly that occurred in the second decade of the seventeenth century, for Constantijn Huygens reported seeing such an instrument on a visit to London in 1621, and the earliest known representation of a microscope is Isaac Beeckman's drawing of 1631. The instrument was named 'microscopium' in 1625 by members of the Accademia dei Lincei in Rome.

To extend the eye's capacity to see minute objects, either a single lens or a combination of two or three lenses may be used. Since the telescope was the immediate forerunner of the microscope, the idea of using combinations of lenses to form the compound microscope could be expected to arise. In the seventeenth century, however, there were drawbacks to the use of the compound instrument so serious that better results could be achieved with the single lens of the simple microscope.

The quality of glass available was poor by modern standards, colored and marred by bubbles. The clarity of the image was also affected by two kinds of aberration, chromatic and spherical. The former, caused by the unequal refraction of light rays, produced a colored edge to the image. The latter resulted from the spherical curvature of lenses that caused spread rather than sharp focus, and therefore a blurred image. The history of the development of the microscope is of attempts to banish these defects.

The single-lens microscope was less affected than the compound by these problems, and was therefore of greater scientific importance during the first two centuries of the microscope's history. Chromatic aberration was minimized because with a single lens the eye sees a virtual image, with the colors superimposed, while spherical aberration can be lessened by reducing the aperture and using an intense light source (usually skylight).

The first major optical improvement was initiated by John Dollond, who corrected chromatic aberration in the telescope by using a combination of crown and flint glass for the lenses in 1758. The greater technical problems of achieving the same correction to the much smaller lenses of the compound microscope was solved by the Amsterdam instrument-maker Harmanus van Deijl at the end of the eighteenth century. Spherical aberration had to wait until 1830 for its solution, by Joseph Jackson Lister. What did improve steadily through these two hundred years was the design of the microscope stand, aiming always at greater stability, finer adjustment, and more satisfactory illumination.

### The Simple Microscope

The capacity of the simple microscope to achieve high resolution was dependent upon the skill and concentration, as well as excellent natural sight, of the observer. The instrument, because it focused close to the eye, was best suited for looking at transparent objects by transmitted light. A small number of skilled seventeenth-century microscopists achieved remarkable results with the simple microscope.

Antoni van Leeuwenhoek, a cloth merchant of Delft, used a tiny lens contained in a metal plate, with a spike to hold the specimen close to the lens; the instrument was then hand-held immediately in front of the eye. Leeuwenhoek made his own lenses from beads or blown bulbs of glass, and with skill and patience he achieved a resolution of about 2 urn. His research, particularly into the reproductive system, was embodied in a series of letters presented to the Royal Society of London. To observe the circulation of the blood in the tail of a fish, Leeuwenhoek devised a different instrument, with a frame holding a glass phial.

Johan van Musschenbroek, an instrument-maker of Leiden, made this type of simple microscope commercially. He also devised what became known as the compass microscope, because the two arms are hinged, as well as a flexible specimen holder for low-power observations, using ball joints that were



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known as Musschenbroek nuts. His were the instruments used by Jan Swammerdam, the Amsterdam biologist whose observations refuted the concept of metamorphosis in insects. Other notable users of the simple microscope were Marcello Malpighi, who discovered the capillary circulation of the blood, and Nehemiah Grew, who revealed the cellular structure of plants.

As the use of the microscope became increasingly popular, the simple instrument remained in use because it was readily portable, and well adapted for field observation. The compass design continued and was joined by the screw-barrel, again invented by a Dutchman, Nicolaas Hartsoeker, and introduced into England in 1702 by James Wilson. The screw action was used to hold and focus slides containing the specimens, and the simple barrel shape was highly adaptable for use with a handle or a folding foot and could even be converted to a compound instrument. The most famous stand-mounted version was produced by the London instrument-maker Edmund Cul-peper.

Natural philosophers of the eighteenth century, and Victorian naturalists, continued to use the simple microscope in many forms. There was the Ellis aquatic microscope, incorporating a watch-glass to observe water creatures; the Withering botanic, contained in a small box and designed to erect itself for use when the box was opened; and the Jones cylindrical naturalist's magnifier.

### The Compound Microscope

The compound microscope, close relative of the telescope, achieved instant popularity through the publication of Robert Hooke's Micro-graphia (1665). The earliest compound microscopes were simple barrels, with or without feet, and were held up to the light source when in use. Hooke devised a side-pillar microscope on a solid base that could be used on a table and tilted at the convenience of the user. He described and illustrated the design and showed it with an illuminating arrangement of lamp and bull's eye lens.

The side-pillar was also adaptable for use with transmitted light, a capacity that came into its own in the hands of the London maker John Marshall around 1700. He provided a stage plate attached to the bottom of the pillar that could be replaced with a glass-based trough to hold a fish or frog, so that Harvey's recent discovery of the circulation of blood could be observed. The fish-plate remained a standard microscope accessory for nearly two hundred years.

Henry Baker's Microscope Made Easy (1742) provided another new impetus to microscopy. Baker was a skilled microscopist who studied crystal morphology, and he commissioned the instrument-maker John Cuff to make to his design an all-brass microscope, much more convenient in use and with finer focusing. The Cuff-type microscope, a side-pillar on a box foot containing a drawer for accessories, was copied on the Continent and adapted to fold away into the case, being known as the chest microscope.

Later modifications to the side-pillar were made by George Adams, father and son, and by Benjamin Martin, notable London makers and retailers of instruments in the second half of the eighteenth century. Changes produced a much lighter instrument, often with a folding foot and a ball-joint at the top of the pillar to hold the barrel. More and more elaborate accessories were provided in finely fitted cases.

The compound microscope until the 1830s was the popular tool of the naturalist, botanist, and mineralogist, the majority of whom were satisfied to examine the standard specimens and compare notes with other enthusiasts. Some, doing serious research, were pressing for improvements to the optics of the instrument. Chromatic aberration was removed at the end of the eighteenth centurv The early years of the nineteenth century were filled with attempts to solve spherical aberration, including the attempt to use jewel lenses in place of glass. The breakthrough came with Lister's discovery of 1830, heralding the great age of the optical microscope

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#### 14.6.1.1 Petrographic Microscopes[1558]

**REWORK:** For the measurement of the optical properties of minerals the petrographic microscope is the most important instrument available to mineralogists. Its development did not follow immediately upon the introduction of the reflecting goniometer. During the years 1814 to 1818 Sir David Brewster wrote a series of papers announcing his discovery of biaxial crystals and of the intimate relations between optical and crystallographical relations in crystals. In 1828 William Nicol, the inventor of the nicol prism, ground thin sections of rocks and mounted them in Canada balsam. In 1850 H. Clifton Sorby studied thin sections of rocks; between 1850 and 1861 he published the results of his investigations of certain rocks and demonstrated the possibilities of the petrographic microscope in the study of thin sections of rocks. He was followed in 1863 by F. E. Zirkel, who described a series of rocks. In 1870 and 1876, H. Rosenbusch constructed a practical petrographic microscope with rotating stage. During that decade interest in the petrographic microscope became general. Such microscopes were manufactured in several countries and some of them are still in use. At the present time a number of petrographic microscopes of satisfactory design and quality are on the market.

The most important optical constants of a mineral for various wave lengths of light are: its principal refractive indices; its principal birefringences; the nature of the optical ellipsoid of reference (index ellipsoid); determination of the spatial relations between the principal planes of its index ellipsoid and its principal crystallographic directions (extinction angles for definite directions and zones).

Refractive indices are measured most easily by the immersion of fine mineral grains in refractive liquids or solids of known refractivity for a given wave length of light at a definite temperature. A number of liquids and mixtures of liquids are available to cover the range in refractive indices between 1.33 and 2.10; and in low melting solids to cover refractive indices up to 3.0 and even in excess of 3.0. For the comparison of the refractive index of a fine mineral grain with that of the surrounding liquid, either the Becke-line method or that of oblique illumination is used. The degree of accuracy attainable by these methods, under carefully controlled conditions, is about 2 in the fourth decimal place; at this limit the difference in intensity of illumination between the Becke-line, or oblique illumination effect, and the general field is just detectable by the eye; below it the gradational contrast is no longer perceptible to the eye. Determinations accurate to 0.001 in refractive index are easily

[1558] Further historical information may be found in: William Benjamin Carpenter., *The microscope and its revelations*. Sixth edition. New York, William Wood and Co., 1883. 2 vols. • Daniel E. Kile., "Historical development of the petrographical microscope," *Mineralogical Record Publication Number One*. Tucson, 2003. 96 p., illus. [Elaborate, full history of the instrument with many fine illustrations.] • R.J. Sigsby., "A brief history of the petrographic microscope," *The Compass*, **43** (1966), no. 2, p. 94-103. • Herbert G. Smith., *Minerals and the microscope*. London, Thomas Murby & Co,, 1927. 116 p.

made on favorable grains measuring only a few microns in diameter. For measurements in different parts of the spectrum, either the liquid mixture must be changed or the same liquid held at different temperatures. The decrease in refractive index of a liquid is commonly 0.001 per 2° to 3° C. rise in temperature. Determinations of the refractive indices of liquids are made either with the aid of a total reflecting refractometer or by the prism method on a spectrometer or goniometer. In either case only a drop of the liquid is required.

Birefringence measurements are made on crystal plates of uniform, known thickness by use of a birefracting graduated wedge or by tilting a plane-parallel plate to compensate the path difference produced by the mineral plate. In this measurement the thickness of the mineral plate is the chief element of uncertainty. Optic axial angles are determined by imaging the interference figure, formed in convergent polarized light, on a finely divided coordinate scale in the focal plane of a positive eyepiece; the scale may also be placed in the lower focal plane of the substage condenser and may then be graduated to read off angular distances directly. The angular equivalent of each scale division is ascertained either by computation or preferably by direct determination with the aid of an Abbe apertometer or of the collimator of a goniometer. The optical character of a birefracting mineral is ascertained by use of a birefracting plate or wedge of known orientation.

Experience has shown that it is possible to determine these optical properties, and other less important optical characteristics, on mineral grains measuring only one one-hundredth millimeter in diameter.

Thin sections of rocks and of mineral aggregates are used primarily for the study of the morphological development of the various minerals and the relations between the mineral grains, rather than for the accurate measurement of their optical properties. With the Fedorov stage, however, determinations of optic axial angles and of positions of the planes of optical symmetry relative to crystallographic directions, especially in the feldspars, are made on thin sections of rocks. In recent years the Fedorov stage has been employed with great success in petrofabric analysis, to ascertain for a given mineral, such as quartz, the relative frequency of occurrence or distribution in space of a given crystallographic direction, such as the principal or optic axis. From this study of grain orientation in a rock mass, by use of sections cut along definitely known planes in a rock specimen whose orientation in the field has been ascertained, information is gathered on the present structure of the rock mass and on its deformation in the past. This combination of field and laboratory study is directly dependent on the information yielded by measurements with the Fedorov stage which in this field of scientific inquiry is indispensable.

## Polarizing Microscopes

The instruments necessary for the study of the optical properties of crystals developed in parallel with the theoretical work. Biot (1816) produced an instrument with polarizer and analyser but no lenses. Nicol described his polarizing prism in 1829. Amici (1844) was probably the first to use lenses in conjunction with polarizer and analyser. Compensators for the measure-ment of double refraction were introduced by Brewster (183Oa-c), Babinet (1849), Michel-Lévy (1883) and Berek (1913). Following the observation made by Malus (1808) that light reflected from transparent surfaces is partially polarized, Jamin (1850) made precise measurements of the intensities of polarized beams reflected from many different transparent and absorbing crystals. The Amici-Bertrand lens was introduced by Bertrand in 1878. The universal stage for the polarizing microscope was introduced by Fedorov (1891) and greatly developed by Berek (1931, 1937).

The use of polarized light in conjunction with the microscope has been the means of adding considerably to the usefulness of this instrument for particular branches of science. Among these, perhaps geology must have the first claim, for Sorby's original work in this connection dates back to i860. Much valuable work has been done with the polarization microscope since that time, and in more recent



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years it has become of service to workers in the fields of biology and metallurgy.

Giovan Battista Amici devised a polarizing microscope around 1830, and instruments of this sort came into common use for petrographic and crystallographic work in the second half of the century. The cyanopolarimeter enabled one to compare the color of the sky with the colors produced by a polarization system.

The appearances of certain kinds of objects when viewed through the polarization microscope considerably assist the microscopist in the identification of a specimen, and this in a manner not possible by ordinary observation with unpolarized light. For instance, the identification of minute particles of crystals, minerals, etc., can be effected by this means; in biological specimens differentiation of fibrous membranes in other tissue may be greatly facilitated; and in metallurgical specimens inclusions may sometimes be identified and stress effects observed.

The development of the petrographic microscope near the end of the 19th century facilitated rapid advances in mineralogy and geology. Early studies in France and Germany elucidated the identification of important rock-forming minerals, including the feldspar, amphibole, pyroxene, and mica group minerals. Rocks could thereafter be classified based on trace mineral constituents, and fine-grained rocks which were previously intractable could also be classified by microscopical studies.

Improvements in mechanical and optical design led to increasingly accurate measurements of the optical properties of minerals. Microscopes continued to evolve toward heavier, modular units that accommodated an increasing array of sophisticated accessories. The commercial introduction of Polaroid in the mid-1940s facilitated the adaptation of binocular heads, while optics evolved from simple achromats to flat-field, coated lens systems.

Methods in microscopical petrography were advanced in the mid-19th century by Sorby in England, subsequently taken up by Rosenbusch and Zirkel in Germany, and thereafter adopted by King in the United States. By the early 20th century, American workers had made notable contributions, particularly in their introduction of reflected light methods for ore microscopy. The early emphasis on descriptive petrology (characterized by the magnificent chromolithographs of the late 19th century) was supplanted in the 20th century by applied and theoretical studies.

Surprisingly accurate work was done in the late 19th and early 20th centuries with instruments that many would consider primitive by todays standards. These instruments show an elegance in form and function not seen in modern microscopes. It is important to recognize the historical significance of these microscopes and accessories, and to insure their preservation as a part of our mineralogical heritage.

The decline in the use of the petrographic microscope began in the mid-1970s. However, it remains one of the most effective tools for mineral identification, and it is unfortunate that it is now often overlooked.

It's a rare student who is not captivated by the first sight of a thin section under crossed polarizers with a petrographic microscope. Many students who are ultimately captured by pe-trography develop a relationship with microscopy that is one of continuous fascination. More modern analytical instrumentation has revolutionized petrology, but the enduring role of optical pe-trography calls directly to one of our most powerful senses, with a direct feed to the analytical brain in ways that remote inspectionof samples crushed, vaporized, or loaded in vacuum chambers cannot claim. Optical petrography is old but it retains a unique and fundamental role in mineralogy and petrology.Daniel Kile's monograph on The Petrographic Microscope is at first glance a piece devoted to beautiful old brass instruments. This impression is excusable because of the 93 color photographsthat he has compiled, many of which illustrate superbly built mi-croscopes and associated attachments of an earlier era. However, Kile is clearly one of those students captured to the fascination ofpetrography and he devotes most of his monograph to the story of how optical petrography evolved over time. The monograph begins with six pages of introduction and description that ex-plain the characteristics of a pet-

rographic microscope in detail sufficient for a reader not familiar with optical petrography. The next six pages similarly explain the basic properties observable with a petrographic microscope, including clear descriptions of the indicatrix and the effects of plane and crossed polarization with parallel and conoscopic light. Kile includes pictures of somethings I had not seen, such as hollow glass teaching models of indicatrices, the positive ones half-filled with red liquid and the negative ones with blue liquid, that allow the student to rotate themodel and see the dimensions and orientations of infinite optic sections. The indicatrix models I knew were still fun to play with but were made of plaster. Following this preliminary material are26 pages devoted to the history of the petrographic microscope, illustrated with many color photographs of instruments dating from 1880 through the 1970s. The history, however, ranges from the definition of Snell's law in 1621 through a description of the Bloss and Light detent spindle stage of 1973. Athree-page table at the end of the section nicely summarizes over 100 milestones in the development of the petrographic microscope.The remaining sections of the monograph are devoted to a his-tory of the manufacturers of petrographic microscopes (5 pages),a detailed section on the many accessories (some long abandoned)that have been developed for the petrographic microscope (31 pages), a section on evaluation and restoration of petrographic microscopes (3 pages), and conclusions, acknowledgements, andreferences (11 pages).

There is no index, but in a monograph of less than 100 pages this is not a serious shortcoming. The text is well written and generally free of errors (I only noticed two minor things that an editor should have caught).I read through this monograph, cover to cover, because I found so much in it that I had not been aware of. My exposure to optical petrography was through teachers with a gift for history as well as a passion for petrography, so I knew some historical details such as the stories of Henry Clifton Sorby making admirable Victorian use of his time by grinding thin sections in his lap as he rode trains across England in the mid-19thcentury. I did not know that Sorby delved into microscopy for the measurement of hemoglobin in blood. I had never seen an elliptical analyzer or a Quirke hemisphere (what a neat teaching tool!) I now know whatintegrating stages look like and am grateful that I never had to use one. There's an abundance of detail in these 96 pages.There are a few things that could have used more attention. Those who have spent long hours point counting might be inter-ested in more coverage of manual and automated stages for this purpose.

Developments in light sources and photomicrography could have been described. Nevertheless, Kile has chosen mate-rial of broad interest and compiled it into a very readable and visually pleasing product. This monograph is a great value for mineralogy teachers and students, and especially for people that admire or collect historic scientific instruments.

### 14.6.2 Refractometers[1559]

**REWORK:** All transparent materials bend the light rays that pass through them. The amount or angle by which the ray is bent is called refraction. Isaac Newton described refraction—that is the deviation of a ray of light passing into a transparent material—to its density. William Wollaston [1766-1828] made many theoretical and practical contributions to physics and optics in particular. In 1802 he developed a method for determining refractive indices with the aid of total reflection.[1560] Other studies were conducted in the nineteenth century that showed the refractive index is dependent on the temperature of the object when the measurement is made. Changes in the temperature can cause the index to change because the atoms of the material either expand or contract with variations of temperature. By the 1870s measurement of refractive index was

[1559] Further historical information may be found in: Edmund Hoppe., *Geschichte der Optik*. Leipzig, Verlagsbuchhandlung J.J. Weber, 1926. 262, [1] p., illus. [History of optics.; Reprinted, Wiesbaden, Dr. Martin Sandig oHG., 1967.] • E.-H. Schmitz., *Handbuch zur Geschichte der Optik*. Bonn, 1981-1984. 4 vols. • Alfred E. Tutton., *Crystallography*. London, 1922, **2**, p. 1033-1038.

[1560] W.H. Wollaston., "A method of examining refractive and dispersive powers by prismatic reflection," *Philosophical Transactions*, **??** (1802), p. ??-??.

standardized and instruments known as "refractometers" were created to test the property. These then were manufactured by many of the leading optics firms of the time, including Hilger & Watts in Britain, Bausch & Lomb in the United States, and Zeiss in Germany.

A refractometer is an optical instrument that is used to determine the refractive index of a substance or some physical property of a substance that is directly related to its refractive index. Certain types of refractometers have been devised for measuring gases, liquids, and even transparent or translucent solids such as gemstones. A refractometer can be used to determine the identity of an unknown substance based on its refractive index, to assess the purity of a particular substance, or to determine the concentration of one substance dissolved in another. In mineralogy, they are used to determine the value of the refractive index of the transparent crystal.

Depending on the state of the substance under investigation (i.e., gas, liquid, or solid), refractometers have employed a variety of optical principles to make their measurement. The first of these is the angle of refraction of a ray of light passing through a prism-shaped sample. One form of refractometer is thus essentially a spectrometer incorporating a hollow prism into which the sample liquid is poured. The angle of minimum deviation of this prism is determined, and the index of refraction calculated. In a variation of this principle, the Zeiss "dipping" refractometer consists of a viewing telescope immersed in the sample liquid to observe the refraction of the rays from a light source located outside the glass wall of the container (see spectrophotometer).

A second physical principle employed is that of total internal reflection. In passing from a lower-index to a higher-index medium, light is completely reflected at the interface when the tangent of the angle of incidence is greater than the ratio of refractive indices. In the refractometer of Ernst Abbe, the liquid sample is either sandwiched between two prisms or dropped onto the top of a single prism. A telescope on a graduated circle is used to observe the line of total reflection. Because the index of refraction varies significantly with temperature, the instrument often incorporates a means of measuring and adjusting the sample temperature. The refraction through the prism also disperses the light, causing a colored fringe. This is sometimes removed by interposing a compensating unit consisting of two Amici prisms. Alternatively, the instrument can be used with monochromatic light. The refractometer of Carl Pulfrich also measures the critical angle for total internal reflection, employing a right-angled prism onto which the sample liquid is placed. Solid samples can be measured by mixing them with an index-matching liquid (which causes the total reflection to disappear) and then measuring the liquid in the refractometer.

The Nichols microrefractometer determines the index of refraction of a liquid by measuring, through a microscope, the displacement of a line viewed through two prisms oriented in opposite directions and covered with the sample liquid. The deviation is calibrated with respect to a series of reference liquids of graded refractive index.

Another method relies on the disappearance of a solid transparent object when its refractive index matches that of the liquid. A series of reference solids are employed, which may be powders, single particles, or fibers if a microscope is used for examination. Conversely, unknown solid samples in this form can be measured if reference liquids are available. The microscopic immersion method is in fact the most frequently used technique for solids, for which a smooth refracting surface can be difficult to obtain.

Ernst Abbé constructed his first refractometer in 1869.[1561] Five years later, in 1874, he published a comprehensive booklet, in which he discusses the theory and described instruments for the measurement of refractive index using prisms and by total reflection.[1562]

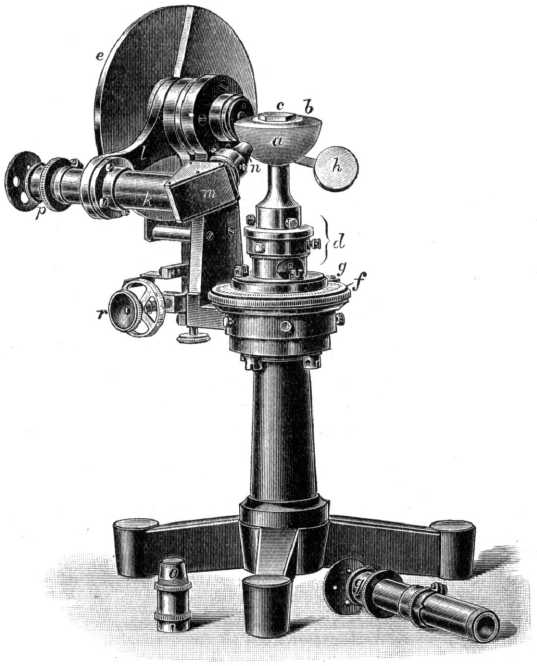
At the Carl Zeiss Optical Factory,

[1561] Joachim Wittig., *Earnst Abbe.* Leipzig, Teubner Verlagsgesellschaft, 1989, p. 60.

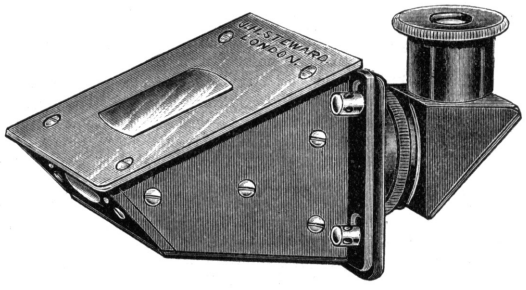
[1562] E. Abbé., *Neue Apparate zur Bestimmung des Brechungs - und Zerstreuungsvermögens fester und fluüssiger Körper.* Jena, Mauke's Verlag, 1874.

Ernst Abbe [1840-1905] invented the 'Abbe refractometer' for determining the refractive index of substances and improved photographic and microscopic lenses.[1563]

C. Pulfrich., *Das Totalreflectometer und das Refractometer für Chemiker, ihre Verwendung in der Krystalloptik und zur Untersuchung der Lichtbrechung von Flüssigkeiten.* Leipzig, 1890. x, 144 p. [BL, 8716.cc.30.]



Abbe's Refractometer (c1911)




Smith's Refractometer (c1911)

Seeing the utility of using refractive index in determining gemstone authenticity, Herbert Smith developed a convenient pocket refractometer.[1564] The cut stone placed on a flat glass and light is passed through the object and a reading made from the eyepiece.

Notes...[1565]

Notes...[1566]

Notes...[1567]

Notes...[1568]

Other References:

Allen, Roy Morris. Practical Refractometry by Means of the Microscope: With Listings of Index Liquids, and Other Aids for Mineralogists. New York: R.R Cargille Laboratories, 1954.

Batsanov, S.S. Refractometry and Chemical Structure. Translated by Paul Porter Sutton. New York: Consultants Bureau, 1961.

Lewin, S.Z. "Refractometry and Dispersometry." In Treatise on Analytical Chemistry, edited by I.M. Kolthoff, Philip J. Elving, and Ernest B. Sandell. Vol. 6. New York: Wiley, 1965.

Longhurst, R.S. Geometrical and Physical Optics. 3rd ed. London: Longman, 1973.

Soret, Charles., "Ueber ein Refractometer zur Messung der Brechungsexponenten und der Dispersion fester Körper," ??, **1883**, p. ??-??, one plate.

Literature

1893 J. Traube., *Physikalisch-chemische Methoden.* Hamburg und Leipzig, Verlag von Leopold Voss, 1893. 234 p.

### 14.6.3 Dichroscopes[1569]

**REWORK:** In some transparent minerals the property of pleochroism is apparent. This is the property where the color of the mineral

[1563] Richard A. Paselk., "The evolution of the Abbé refractometer," *Bulletin of the Scientific Instrument Society*, **62** (1999), p. 19-22. [History of the refractometer developed by Ernst Abbé (1840-1905).]

[1564] Herbert Smith., "???," ???, **??**, p. ??-??.

[1565] S. Czapski., "???," *Zeitschrift für Instrumente Kunde*, **10** (1890), p. 246.

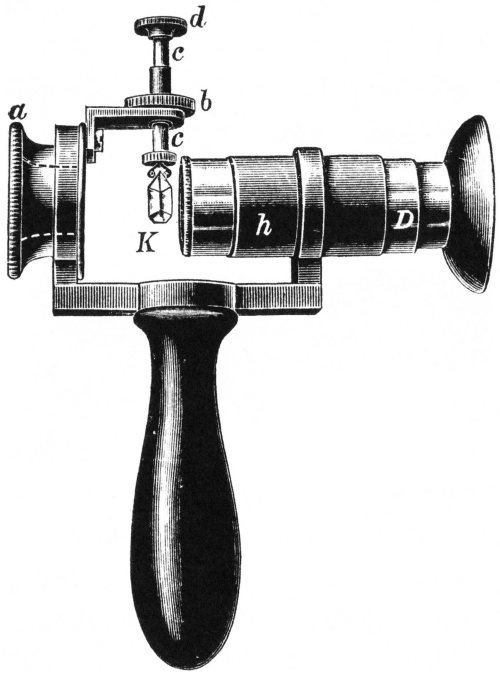
[1566] Paul Groth., *Physikalische Krystalllographie.* Thrid edition. München, 1895, p. 676.

[1567] Th. Liebisch., *Grundriss der Krystallographie*, 1896, p. 259.

[1568] C. Leiss., "???," *Neues Jahrbuch für Mineralogie*, **1897** I, p. 78; (1898), II, p. 65.

[1569] Further historical information may be found in: N.W. Thibault, "A simple dichroscope," *American Mineralogist*, **25** (19—), p. 88-90. [Contains references to the earlier literature.]

noticeablly changes when it is viewed from different angles. Tanzanite, a blue gem variety of the mineral Zoisite ($Ca_2Al_3(SiO_4)_3(OH)$) can in transparent crystals show the three distinct colors of blue, purple, and darker blue, when the crystal is viewed along each of its crystallographic axes. An instrument used to test for this property in crystals is a dichroscope, which is a tool that lets you view a crystal from two different angles similtaneously, and compare side-by-side the colors seen. It is a useful and fast test that separates authentic stones from other simliar material. Ruby, another pleochromatic gemstone, can, for example, be discriminated from its natural simulants like red spinel, garnet and also from glass, by testing for the property. Most rubies show distinct purplish red and orangey red colors pleochroic colors, and the dichroscope displays them side by side for easy comparison.




Doelter's Dichroscope (c1899)

In 1820, the Scottish physicist David Brewster noted that some crystals had the property of dichroism.[1570] It was eventually realized that the property could be useful in distinguishing certain minerals, and an instrument was invented to measure the property. In 1829, Henry James Brooke describes an instrument similar in principles to the dichroscope,[1571] but many mineralogical textbooks attribute the invention of the instrument to Wilhelm Haidinger in 1845.[1572] This tool was further developed and improved upon by Dove,[1573] Lang,[1574] Halle,[1575] and A. Cathrein.[1576] The dichroscope was also conbined with the spectroscope by Leiss.[1577]

Cornelius Doelter who did much work on the investigation of precious stones designed a portable instrument for the on-site investigation of polished gemstones as well as rough material. It includes a handle for comfortably holding the device and was manufactured by the firm of Fuess (see figure).[1578]

Newman W. Thibault described a simple dichroscope, which contains references to the earlier literature.[1579]

### 14.6.4 Polarized Light Measurment

**REWORK:** Light is made of two waves moving similtaneously through space but with the wave at a 90° angle to each other.

The study of polarization began in 1669, when Erasmus Bartholin observed that a

[1570] David Brewster., "On the phenomena of Dichroism or the Absorption of Common Light by crystallized bodies," *Edinburgh Philosophical Journal*, **3** (1820), p. 243-247.

[1571] H. Brooke., *Am. J. Sci.*, **15** (1829), p. 369-372.

[1572] W. Haidinger., "Ueber den Pleochroismus der Krystalle," *Ann. Phys.*, **65** (1845), p. 1-30. • *ibid.*, "Ueber die dichroskopische Loupe," *Sitzungsber. Akad. Wiss. Wien, Math.-Naturw. Klasse*, **1** (1848), p. 70-75.

[1573] H.W. Dove., "Das Dichrooskop," *Ann. Phys.*, **110** (1860), p. 265-78. [Much larger instrument than that invented by Haidinger in 1845.]

[1574] Viktor von Lang., "Optische Notizen," including "Verbesserte dichroskopische Lupe," *Sitzungsber. Akad. Wiss.*, Wien, **82** (1881), no. 2, p. 171-179.

[1575] G. Halle., *Neues Jahrbuch für Mineralogie*, **1895**, part 2, p. 247-248.

[1576] A. Cathrein., *Zeitschrift für Instrumentenkunde*, **16** (1896).

[1577] C. Leiss., *Neues Jahrbuch für Mineralogie*, **69** (1898), part 2.

[1578] T. Liebisch., *Grundriss*, 1891, p. 311. • Leiss, *Die optischen Instrumente*, 1899, p. 180-181. • P. Groth., *Physical Krystallographie*, 1895, p. 679.

[1579] N.W. Thibault, "A simple dichroscope," *American Mineralogist*, **25** (19—), p. 88-90.

transparent crystal of Iceland spar ($CaCO_3$) could split a beam of light into two different rays. Christian Huygens studied double refraction a few years later and described some of the effects that we now recognize as polarization of the ordinary and extraordinary rays. But only since the beginning of the nineteenth century has polarization been systematically investigated.

In Paris in 1808, Etienne Malus discovered that light could be polarized by reflection, and he coined the term "polarization." Polarization attracted the immediate interest of such leading physicists as Francois Arago, Jean Baptiste Biot, and Augustin Fresnel in France, and David Brewster in Scotland. Around 1820, by assuming that light is a transverse wave, Fresnel was able to explain in mathematical terms the phenomena of double refraction and polarization. As the relationship between the optical activity of substances and their molecular structure was recognized, a completely new array of instruments was developed.

1978: Bennett J. and H. Bennett (1978) Polarization. Section 10 in W.G. Driscoll, ed.: Handbook of Optics. McGraw-Hill, New York, 164 p. Describes prism types, etc.

#### 14.6.4.1 Polarimeter

**REWORK:** A polarimeter measures the angle of rotation of a polarized plane of a beam of light when it passes through an optically active substance. The basic polarimeter consists of a polarizer (birefringent crystal, polarizing prism, pile of glass plates, or nonmetallic mirror) and a second device of the same kind called an analyzer, which can rotate in the center of a divided circle. A small telescope attached to the latter allows for observations. The early polarimeters worked on an extinction principle that is, when the analyzer and the polarizer are positioned at right angles to one another, no light is transmitted. An optically active solution interposed between the crossed polarizer and analyzer rotates the plane of light and, thus, allows some light to be transmitted. The analyzer is then rotated to reestablish the obscurity of the field of vision.

The polarimeter used by Biot and Malus around 1810 used rotating mirrors of black glass for both the analyzer and the polarizer. In a later model, the analyzer was formed by a prism of Iceland spar. In 1828, the Scottish geologist William Nicol described an efficient polarizing prism composed of two pieces of Iceland spar glued in such a way as to allow the extraordinary ray to pass through while deflecting the ordinary ray. Nicol prisms remained in use until the twentieth century. Other polarizing prisms were proposed by William H. Wollaston, Leon Foucault, Adam Prazmowski, Paul Glan, Silvanus Thompson, and others. In 1844, the German chemist Eilhard Mitscherlich introduced a polarimeter equipped with two nicols. Various optical elements such as quartz plates were subsequently introduced in these instruments in order to further increase their accuracy.

Jean Francois Soleil and his son-in-law and successor, Jules Duboscq, invented and manufactured some of the most successful polarization devices between roughly 1840 and 1880. In SoleiFs saccharimeter, the rotation of a polarized beam of white light produced by a sugar solution was compensated for by a double sliding quartz wedge (SoleiPs compensator). Other important instrument manufacturers were Franz Schmidt & Haensch, and R. Fuess (both located in Berlin); Hermann & Pfister (in Bern); Steeg & Reuter (in Homburg); and J.G. Hoffmann and Leon Laurent (in Paris).

The polaristrobometer, invented by Heinrich Wildt in 1865, was equipped with a couple of quartz plates that produced interference fringes. A specific rotation of the analyzer eliminated the fringes, thus allowing one to measure the rotation of the polarization plane.

In 1873, Alfred Cornu and Duboscq proposed a half-shadow polarimeter for yellow monochromatic light. In this instrument, the position of polarization plane was determined by comparing and equalizing the luminous intensity of two (or more) sections of the ocular field. In 1874, Laurent described a similar apparatus that attained great popularity in France. In the 1880s, Ferdinand Franz Lippich conceived a half-shadow polarimeter in which the analyzer was composed of a couple of

Glan's prisms. This instrument was eventually improved by Hans Heinrich Landolt.

Literature

1893 J. Traube., *Physikalisch-chemische Methoden.* Hamburg und Leipzig, Verlag von Leopold Voss, 1893. 234 p.

### 14.6.4.2 Polariscope[1580]

**REWORK:** A polariscope is an instrument that tests for a mineral being double or single refractive, and will allow us to find the various crystal axis of the stone. It is an optical device consisting of two polarizers with a space between for a crystal or rock under study, from which it derives its name. The polariscope allows the user to actually see the path that those beams are taking through the stone. By knowing that the stone is double refractive, we can use the optic interference figure to actually find the various optical directions that the light is traveling through the stone, and thereby make identifications based on this information.[1581]

A polariscope enables an observer to see the effects of polarization, but not measure their extent. Because polarization phenomena were deemed spectacular, polariscopes were widely used in physics demonstrations. They were often sold with a series of uniaxial and biaxial crystal plates which, in polarized light, exhibit splendid interference patterns and colors. Different types of polariscopes were used in connection with heliostats and magic lanterns.

Small presses were also used to produce birefringence in glass plates. Around 1830, the German chemist Christian Norremberg invented a vertical polariscope in which light was polarized by an inclined glass plate and analyzed by a black mirror or a nicol. This enjoyed popularity for many decades. Around 1850, Duboscq introduced a sophisticated projection polariscope that was eventually copied by several instrument-makers. Many similar devices were proposed, but their working principle remained the same.

Henry James Brooke., "Description of the Polariscope, an instrument for observing some of the most interesting phenomena of Polarized Light," *American Journal of Science*, **15** (1829), p. 369-373.

Auguste Bravais., "Description d'un nouveau polariscope, et recherches sur des doubles réfractions peu énergiques," *Paris, Comptes Rendus*, **32** (1851), p. 112-116; *Annals de Chimie*, **43** (1855, p. 129-149; *Annals der Physik*, **96** (1855), p. 395-414.

Giovan Battista Amici devised a polarizing microscope around 1830, and instruments of this sort came into common use for petrographic and crystallographic work in the second half of the century. The cyanopolarimeter enabled one to compare the color of the sky with the colors produced by a polarization system.

1875: Adams W.G. (1875,1879) A new polariscope. Phil. Mag. 50, 13-17. Measuring polariscopes. 8, 275-277.

1876: Bosanquet R.H.M. (1876) On a new form of polariscope, and its application to the observation of the sky. Phil. Mag. 2, 21-28. Improvement on Savart's polariscope.

1879: Becke F. (1879) Ein neuer Polarisations-Apparat von E. Schneider in Wien. Mineral. Petrogr. Mitth. 2, 430-437. See also Schneiders paper in Carls Rep. 15, 744-754.

1885: Ahrens C.D. (1885) On a new form of polarizing prism. Phil. Mag. 19, 69-70. From J. Royal Microsc. Soc.

1908: Bates F.J. (1908) A quartz compensating polariscope with adjustable sensibility. U.S. National Bureau of Standards Bull. 4, 461-466 og 5, 193-198.

Khvolson, O.D. Traite de physique. Paris: A. Hermann, 1908-1914.

1915: M. Berek., "Ueber Neueinrichtungen am Polarisations-Mikroskop," *Zeitschrift für Kristallographie*, **55** ((1915-20), p. 615-626.

Pellin, Philibert. "Polarimetres et saccharimetres." Journal de physique theorique et applique 4 (1903): 436-42.

Rosmorduc, Jean. La polarisation rotatoire naturelle, de la structure de la lumiere

[1580] Further historical information may be found in: F.J. Cheshire., "The Presidents Address: The early history of the polariscope and the polarizing microscope," *J. Royal Microsc. Soc.* **43** (1923), p. 1-18.

[1581] F.J. Cheshire., "Polariscopes: A few typical forms of early instruments in the South Kensington museum," *Transactions of the Optical Society*, *23* (1922), p. 246-255. [**AzU HAS INTERNET SUBSCRIPTION**]

a celle des molecules. Paris: A. Blanchard, 1983.

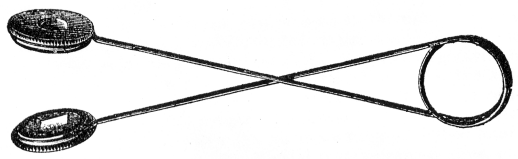
Sidersky, David. Polarisation et saccharimetrie. Paris: Gauthier-Villars, G. Masson, 1895.

Another reference....[1582] [1583] [1584]

### 14.6.4.3 Tourmaline Tongs[1585]

**REWORK:** Tourmaline is also used in the form of a polariscope called tourmaline tongs. Tourmaline crystals are doubly refracting. That is an incoming ray of light is split into an ordinary and an extraordinary ray, which are polarized at right angles to each other. However, the extraordinary ray or E-ray is rapidly absorbed, so if the crystal through which the light passes is only a few millimeters thick, the transmitted light is linearly polarized.

The tongs have a tourmaline crystal in each half, mounted with the transmission axes at right angles to each other. Transparent crystals, such as thin plates of mica or other transparent mineral plates are slipped between the two halves of the tongs, and observed by holding the instrument up to the eye. The system does not work very well because tourmaline does not easily transmit light. About 1816 Biot discovered that plates of tourmaline show double refraction, but absorb the ordinary ray. This led him to the construction of the well-known tourmaline tongs for the study of polarization phenomena. The device was first described by the French mineralogist Jean-Baptiste Biot [1774-1862] in a series of papers describing polarization and refraction in crystallized substances.[1586]



Tourmaline Tongs

In the tourmaline tongs, first described about 1826 by Carl Michael Marx [1794-1864], the specimen to be observed was inserted between two pieces of tourmaline, a birefringent and dichroic crystal that absorbs most of the ordinary ray while allowing the extraordinary ray through.[1587] Marx cut two thin, flat plates from a Tourmaline parallel to the c-axis. By placing the plates in sequence, one on top of the other and viewing through them, the amount of light passing through the slices would gradually reduce as one of the slices was turned against the other through 90°. By placing these plates on two sides of a pair of connected tongs, it was possible to make a simple instrument for testing polarization in objects, including minerals, placed between the tourmaline slices.[1588]

### 14.6.4.4 Conoscopes

**REWORK:** The conoscope, is an accessory tool to the polariscope. It allows visualizing the optical axes of a birefringent and transparent mineral. It is a polarizing microscope designed

[1582] Charles Woodward., *A familiar Introduction to the study of Polarized light; with a description of, and instructions for using, the Table and Hydro-Oxygen Polariscope and Microscope*. London, 1848. [BL, 8715.d.36.]

[1583] Edwin Lankester., *Half-hours with the microscope* ... A new edition, with chapter on the polariscope by F. Kitton, and illustrations by Tuffen West. New edition. With eight plates. London, C. Arthur Pearson, 1905. xxiv, 118 p.

[1584] Hans Heinrich Landolt., *Handbook of the Polariscope, and its practical applications*. Adapted from the German edition ... by D. C. Robb ... and V. H. Veley ... With an appendix by I. Steiner, etc. London, Macmillan & Co., 1882. xvi, 262 p.

[1585] Further historical information may be found in: A. Bertin., "Ueber die idiocyclophanischen Krystalle," *Zeitschrift für Kristallographie*, **3** (1879), p. 449-470. [Gives much on the history of polarization applied to mineralogical problems.]

[1586] J.B. Biot., "Sur de nouvelle rapports qui existent enttre la reflexion et la polarisation de la lumière par les corps cristallisés", *Mémoires de l'Institute*, **12** (1812), ??-??. • *ibid.*, "Observations sur la nature des forces qui partagent les rayons lumineux dans les cristaux doués de la double réfraction," *Mémoire Iu à Academie d. Sciences*, 5. Déc. 1814, p. 221-234. • *ibid.*, "Sur un mode particulier de polarisation qui s'obserte dans la Tourmaline," *Paris, Soc. Philom. Bull.*, 1815, p. 26-27, reprinted *Annalen des Chimie*, **94** (1814), p. 191-199 and *Journal des Mines*, **37** (1815), p. 387-8. • *ibid.*, "Découverte d'une différence physique dans la nature des forces polarisantes de certains cristaux.," *Paris, Soc. Philom. Bull.*, **1814**, p. 173-174.

[1587] Carl M. Marx., "Lichtpolarisirung der Dichroits," *Schweiggers Journal*, **49** (1826), p. ??-??. • *ibid.*, "??????," *Annalen der Physik*, **8** (1826), p. 249.

[1588] Hoppe, *Geschichte der Physik*, 1926, p. 269 • *ibid.*, *Geschichte der Optik*, 1926, p. 83.

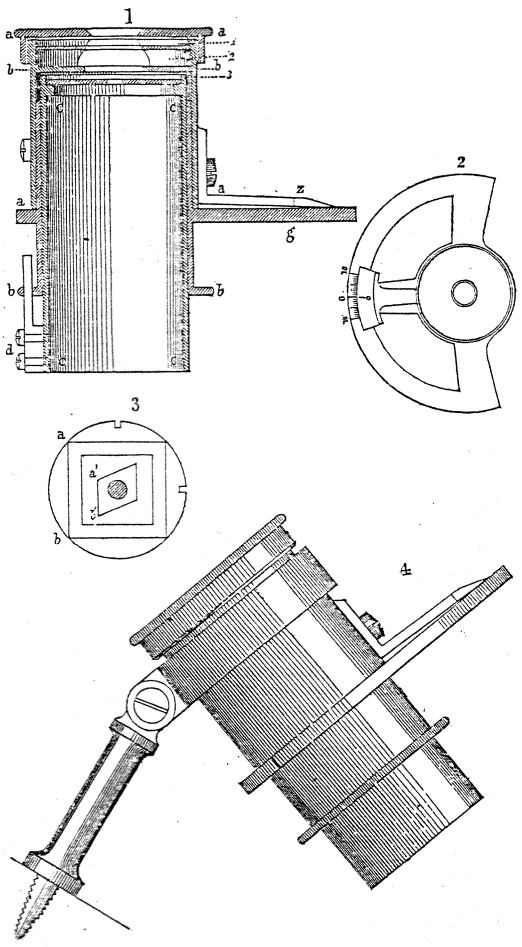
to examine the transmission property of a sample plate at various directions of incidence simultaneously.

The use of polarized light in conjunction with the microscope has been the means of adding considerably to the usefulness of this instrument for particular branches of science. Among these, perhaps geology must have the first claim, for Sorby's original work in this connection dates back to i860. Much valuable work has been done with the polarization microscope since that time, and in more recent years it has become of service to workers in the fields of biology and metallurgy.

The appearances of certain kinds of objects when viewed through the polarization microscope considerably assist the microscopist in the identification of a specimen, and this in a manner not possible by ordinary observation with unpolarized light. For instance, the identification of minute particles of crystals, minerals, etc., can be effected by this means; in biological specimens differentiation of fibrous membranes in other tissue may be greatly facilitated; and in metallurgical specimens inclusions may sometimes be identified and stress effects observed.

### 14.6.4.5 Stauroscopes

**REWORK:** The stauroscope is a type of polariscope used to determine the direction of light polarization in a crystal for accurate measurement of angles of extinction. A type of polariscope used to determine the direction of light polarization in a crystal for accurate measurement of angles of extinction. Kobell in 1855 invented the stauroscope for the study of the optical properties of crystals. A stauroscope is an optical instrument, developed by the Munich mineraologist Wolfgange Von Kobell in 1855 to deterimine the position of planes of light-vibration in crystals.[1589]




Kobell's Stauroscope, 1855

A. Brezina followed Kobell with several important papers on the Stauroscope.[1590]

Paul Groth....[1591]

E. Bertrand...[1592]

L. Calderón...[1593]

[1589] F.v. Kobell, "Optisch-krystallographisch Beobachtungne und über ein neues Polariskop, das Stauroskopische," *Gelehrte Anzeigen der München Akademie*, **??** (1855), p. ??-??. • F.v. Kobell, "Stauroskopische Beobachtungen und über ein Complementar-Stauroskop," *Gelehrte Anzeigen der München Akademie*, **??** (1855), p. ??-??. • F.v. Kobell, "On the Staurscope of Prof. Franz von Kobell (translated for this Journal by S.W. Johnson)," *American Journal of Science*, 2nd series, **19** (1855), p. 425-8.

[1590] A. Brezina, "??? ??? ??? ???," *Poggendorff's Annalen*, **128** (1866), 448. • A. Brezina, "Verfahren mit dem Stauroskop," *Wied. Ann. Phys. und Chemie*, **130** (1867), 3p. • A. Brezina, "??? ??? ??? ???," *Poggendorff's Annalen*, **130**, 141.

[1591] P. Groth, "??? ??? ??? ???," *Poggendorff's Annalen*, **144** (1871), 34.

[1592] E. Bertrand, "Vorrichtung zur Bestimmung der Schwingungsrichtung doppelbrechener Krystalle im Mikroskop," *Zeitschrift für Krystallographie*, **1** (1877), 69.

[1593] L. Calderón, "Ueber einige Modificationen des Groth'schen Universalappartes und über eine neue Stauroskopvorrichtung," *Zeitschrift für Krystallographie*, **1** (1877), 68-73.

F. Stöber...[1594]

#### 14.6.4.6 Wollaston Prisms

**REWORK:** A Wollaston prism is an optical device, invented by William Hyde Wollaston, that manipulates polarized light. It separates randomly polarized or unpolarized light into two orthogonal, linearly polarized outgoing beams.

The Wollaston prism consists of two orthogonal calcite prisms, cemented together on their base (typically with Canada balsam) to form two right triangle prisms with perpendicular optic axes. Outgoing light beams diverge from the prism, giving two polarized rays, with the angle of divergence determined by the prisms' wedge angle and the wavelength of the light. Commercial prisms are available with divergence angles from 15° to about 45°.

Wollaston's Contributions to Optics: In 1820 he invented what has come to be known as the 'Wollaston prism'. It is a polarizing prism consisting of two calcite components cemented such that they deviate the two emerging beams (which are mutually perpendicularly polarized) by nearly equal amounts in opposite directions.

The Wollaston prism consists of two orthogonal calcite prisms which are cemented together on their base. Their optical axes lie perpendicularly to each other and perpendicular to the direction of propagation of the incident light. Light striking the surface of incidence at right angles is refracted in the first prism into an ordinary (o) and an extraordinary (ao) ray. However, these two rays continue to propagate in the same direction. As the optical axis of the second prism is perpendicular to that of the first, the ordinary ray (o) becomes an extraordinary ray (ao) at the boundary surface. Its refractive index changes from n(o) to n(ao); as n(ao) n(o) the extraordinary ray is refracted away from the axis of incidence. The opposite applies to the original extraordinary ray, now an ordinary ray: overall, therefore, the two partial rays display very different directions.

#### 14.6.4.7 Nicol Prism

**REWORK:** The Nicol prism, so named after its inventor, Nicol, is a device for producing polarized light. It consists of a clear transparent crystal of calcite known as Iceland spar, as it is obtained almost exclusively from caves in certain basalts in Iceland. The vertical faces are natural cleavage faces, in which the end cleavages, inclined 71 degrees to the obtuse edges of the prism, are ground down and polished so as to make an angle of 68 degrees with the obtuse vertical edges. It is then cut diagonally in two parts perpendicular to the short diagonal of the end face. The two parts are cemented together in their original position by Canada balsam, a resin obtained from a species of fir. It has an index of refraction of 1.536. Since calcite is a doubly refracting substance, the Nicol prism refracts a ray of light into two rays the ordinary ray, having an index of 1.658, and the extraordinary ray, having an index of 1.486. The angle at which the two new planes are polished, as well as the angle at which the crystal is cut, are so calculated that the ordinary ray will strike the balsam at an angle greater than the critical angle. Consequently, the ordinary ray is totally reflected and is absorbed in the blackened walls of the cork mountings. The extraordinary ray passes through the balsam as a completely polarized ray which is vibrating in a known direction, namely, parallel to the short diagonal of the calcite rhomb. When two Nicol prisms have their short diagonals parallel, light passes through without being changed except for a decrease in intensity. If one of the nicols is revolved, the light gradually diminishes until the nicols are at 90 degrees to each other, when darkness results.

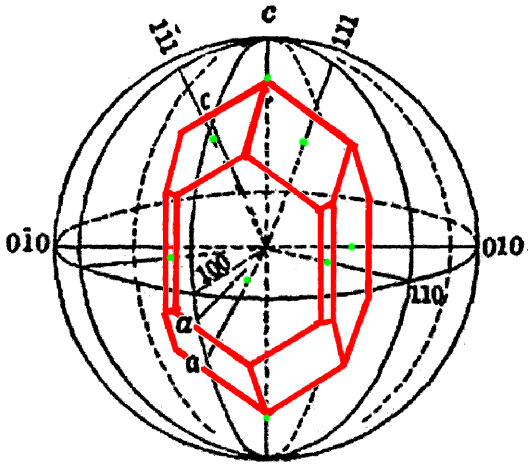
### 14.7 Crystallographic Projections[1595]

[1594] "Ueber ein einfaches Theodolitgoniometer und seine Verwändung zu Stauroskopischen Bestimmungen," *Zeitschrift für Krystallographie*, **29** (1898), 25-32.

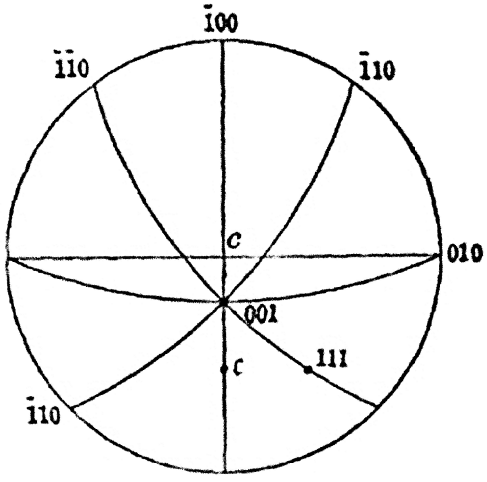
[1595] Further historical information may be found in: L. Burmester., "Geschichtliche Entwicklung des kristallographischen Zeichnens und dessen Ausführung in schräger Projektion," *Zeitschrift für Kristallographie*, **57** (1922), p. 1-47. [Historical development of crystal drawing and projection.] • E. von Federov., "Zur Theorie der Krystallographischen Projectionen," *Zeitschrift für Krystallographie*, **33** (1900), p. 589-598. • A. Hutchinson., "On a protractor for use in constructing stereographic and gnomonic projections on the sphere," *Mineralogical Magazine*, **15** (1908), p. 93-112. [Contains a history of projections from ancient times.] • William J. Lewis., *Treatise on crystallography*.

## 14.7 Crystallographic Projections

Projections are used to reduce three-dimesional information into a conveient 2-dimensional format. In the study of the crystallographical properties of crystals certain projections are extremely useful for providing information to the observer on the spatial relationships of the crystal faces and give the relative positions of facial intersection points. These picutures, once formed, can also highlight the symmetry of a crystal that may otherwise not be apparent.

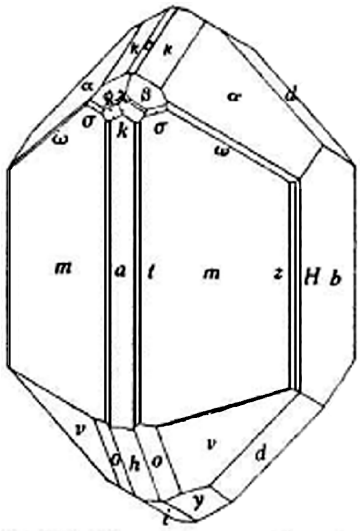



Diopside Crystal in a Sphere




Stereographic Projection of the Diopside

Spherical projections have been widely used in mineralogy to convey information about crystals.[1596] Imagine if a crystal is placed in the center of a sphere, and any point upon it is connected by a straight line with the sphere's center and its surface. This point will be definitely located by the intersection of the line and the surface of the sphere. However, since it is not practical to use a sphere to show how these intersections occur on the surface of the sphere, various techniques have been devised to project the image of the intersections onto a flat surface. Among these the most common to show symmetry are the orthographic, gnomonic, and stereographic projections, with the last the most widely used.




Crystal Drawing of Colemanite

In the following discussion, various projections of a fine colemanite crystal will be reproduced to illustrate the text. Colemanite is a one of the most beautiful mineral borates ($Ca_2B_6O_{11} \bullet 5H_2O$), with its crystals resembling those of calcite in appearance and often large, but with a brighter lusture. In 1885, the species was first described by A.W. Jackson, but in 1902 it was more fully investigated by the noted American mineralogist, Arthur S. Eakle [????-????].[1597] It is from Eakle's

London, 1899.

[1596] Any mineralogical or crystallographic textbook written for the beginner will have a full discussion on the steps needed to create a projection. *Dana's Textbook* for example, contains a long section on developing projections, particularly the stereographic.

[1597] Arthur S. Eakle., "Colemanite from southern

paper that the data and projections are reproduced.

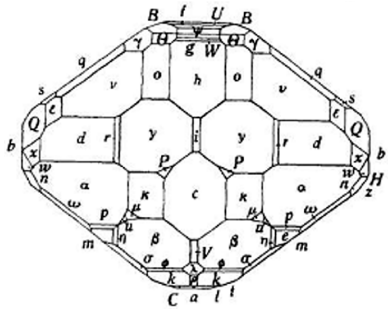
| Face. | Symbol. | | $\phi$. | $\rho$. | $x'$. | $y'$. |
|---|---|---|---|---|---|---|
| | Goldschmidt. | Miller. | | | | |
| $c$ | 0 | (001) | 90° 0′ | 20° 7′ | 0·3663 | 0 |
| $b$ | 0∞ | (010) | 0 0 | 90 0 | 0 | ∞ |
| $a$ | ∞0 | (100) | 90 0 | 90 0 | ∞ | 0 |
| $m$ | ∞ | (110) | 53 53 | 90 0 | 1·3709 | ∞ |
| $l$ | 2∞ | (210) | 69 58 | 90 0 | 2·7419 | ∞ |
| $z$ | ∞2 | (120) | 34 26 | 90 0 | 0·6854 | ∞ |
| H | ∞3 | (130) | 24 33 | 90 0 | 0·4570 | ∞ |
| $\kappa$ | 01 | (011) | 34 0 | 33 13 | 0·3663 | 0 5430 |
| $a$ | 02 | (021) | 18 18 | 48 54 | 0·3663 | 1 0860 |
| $\lambda$ | +20 | (201) | 90 0 | 61 40 | 1·8549 | 0 |
| $i$ | −10 | ($\bar{1}$01) | 90 0 | 20 42 | 0·3781 | 0 |
| $h$ | −20 | ($\bar{2}$01) | 90 0 | 48 18 | 1·1223 | 0 |
| $\beta$ | + 1 | (111) | 63 56 | 51 2 | 1·1106 | 0·5430 |
| $y$ | − 1 | ($\bar{1}$11) | 54 51 | 33 29 | 0·3781 | 0·5430 |
| $d$ | −12 | ($\bar{1}$21) | 19 11 | 48 59 | 0·3781 | 1·0860 |
| $x$ | −13 | ($\bar{1}$31) | 13 4 | 59 7 | 0·3781 | 1·6290 |
| $v$ | − 2 | ($\bar{2}$21) | 45 56 | 57 22 | 1·1223 | 1·0860 |
| $\omega$ | +13 | (131) | 34 17 | 63 6 | 1·1106 | 1·6290 |
| $o$ | −21 | ($\bar{2}$11) | 64 11 | 51 16 | 1·1223 | 0·5430 |
| $k$ | +31 | (311) | 78 12 | 69 22 | 2·5992 | 0·5430 |
| Q | −24 | ($\bar{2}$41) | 27 19 | 67 45 | 1·1223 | 2·1720 |

Angle Measurements of Colemanite

The basis for any crystallographic projection are the measurement of the interfacial angles between faces of the crystal in question. Beginning in the nineteenth century many lists of these measurements began to be published, this due in no small way to the invention of the reflecting goniometer in 1809, which made the determination of these angles relatively easy (see §14.——). As the century progressed the instruments that at first were accurate to only about 1/2 degree quickly improved in precision to hundredths of a degree. The addition of telescopic sights also made it possible to measure very tiny crystals, which in many cases are the best formed. This was important because many times in nature not all the crystal faces are present in each crystal examined, and this is especially true of the larger specimens. Measurements are, therefore, taken on a range of crystals of the mineral in question and the list of all faces observed recorded in the description of angle measurements. Using such a table of angles, it is possible to construct a series of two dimensional projections that represent the physical crystal.

## Orthographic

A perspective view, the orthographic projection was devised by Hipparchus about 150 b.c.e..



Orthographic Projection of Colemanite

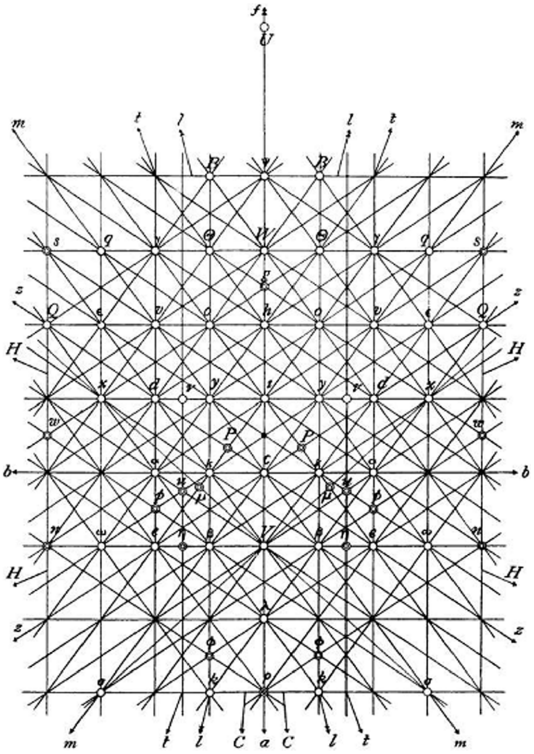
In essence the hemisphere to be projected is viewed from an infinite distance, so that all the lines of sight derived from the object are parallel, with the object being viewed straight on. This illustrative technique is used sparingly in crystallographical work, but is encounted in optical work, notably in interference figures observed with the petrographic microscope. These are always given in orthographic projection that show the interference phenomena observed in convergent polarized light and their measurements are made with this projection. In some nineteenth century textbooks, crystals are drawn in orthographic projection, but this method is inferior and does not illustrate the dimensionality of the object depicted.

## Gnomonic[1598]

About 650 b.c.e., Thales [????-????] intro-

California; a description of the crystals and of the method of measurement with the two-circle goniometer," *University of California, Berkeley, Dept. of Geology, Bulletin*, **3** (1902), p. 31-49, 3 plates.

[1598] H. E. Boeke., *Die gnomonische Projektion in ihrer Anwendung auf kristallographische Aufgaben.* Berlin, 1913. • V. Goldschmidt., *Projection und graphische Krystallberechnung.* Berlin, 1887. • Harold Hilton., "The gnomonic net," *Mineralogical Magazine*, **14** (1904), p. 18-20. • A. Hutchinson., "On a protractor for use in constructing stereographic and gnomonic projections on the sphere," *Mineralogical Magazine*, **15** (1908), p. 93-112. [Contains a history of projects from ancient times.] • E. Mallard., *Traité de cristallographie.* Paris, 1879, **1**, p. 63-66. • H. A. Miers., "The gnomonic projection," *Mineralogical Magazine*, **7** (1887), p. 145-149. • W.H. Miller., "On the employment of the stereographic projection of the sphere in crystallography," *Philosophical Magazine*, **19** (1860), p. 325-328. • Charles Palache., "The gnomonic projection," *American Mineralogist*, **5** (1920), p. 67-??. • Austin F. Rogers, "The gnomonic projection from a graphical standpoint," *School of Mines Quarterly*, **29** (1907), p. 24-33. • G. F. Herbert Smith., "On the advantages of the gnomonic projection and its use in the drawing of crystals," *Mineralogical Magazine*, **13** (1903), p. 309-321. • *ibid.*, "Ueber die Vorzuge der gnomonischen Projection und über ihre Anwendung beim Krystallzeichnen," *Zeitschrift für Krystallographie*, **39** (1903-4), p. 142-152.



Gnomonic Projection of Colemanite

duced the gnomonic projection, which is especially useful in crystallography for plotting the polar and azimuthal angles of measurement. The crystal zones are represented by straight lines. The limitation of the projection is, however, its large distortion and the fact that polar angles in excess of 70° are not convenient to plot. The German crystallographer Viktor Goldschmidt and his school championed this method during the late ninteenth and early twentieth century, and although they published widely about its virtues, gnomonic projects are rarely encountered in non-German books. Projections of this type are somewhat difficult to read, due to their bizzare look, but they do have the advantage that this projection lends itself readily to the preparation of crystal drawings.

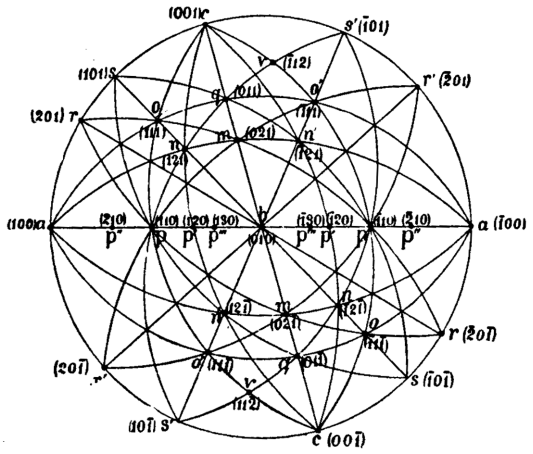
The gnomonic project is created by assuming the crystal is located in the center of an enclosing sphere. Vectors are then projected from the center of the sphere through the center of the crystal faces. The projection is then created by assuming the observer to be located at the center of the sphere and the lines of intersection are projected back. It was in this context that Franz Ernst Neumann [1798-1895] professor of mineralogy and physics at Konigsberg (now Kaliningrad) made the first use of the stereographic projection in geology. In his important and pioneering work *Beiträge zur Krystallonomie* (Contribution to Crystallonomy) he applied for the first time stereographic, gnomonic, clinographic, and linear projection techniques to crystallographical problems. This first alerted mineralogists and crystallographers to the potential use of projections for the representation of crystal forms. However, it did not illustrate any of the crystallographic nets, so important in later work. He proposed instead the arduious task of using a compass and ruler to individually construct each projection. Neumann's idea was also later on, further developed by William H. Miller in Cambridge in 1839, who successfully applied the technique to create his "Miller Indices."

In 1867 the Finnish mineralogist Axel Gadolin [1828-1892] recognized that crystals should belong to the same crystallographic class if they have the same, identically located, symmetry elements and he illustrated the possible configurations of these using the gnomonic and stereographic projections. Mallard in his important and influential *Traité de Cristallographie Geometique et Physique* (Treatise on Geometrical and Physical Crystallography) of 1879 did much to raise the interest in the use of both both the stereographic and gnomonic projections in crystallography. He illustrates numerous examples in of both in the Atlas of crystal forms that accompanied the work.

### Stereographic[1599]

The method of representing the surface of a globe in stereographic projection appears to have been invented by the astronomer

[1599] V. Goldschmidt., "Ueber stereographische Projection," *Zeitschrift für Kristallographie*, **30** (1899), p. 260-271. • R.J. Howarth., "History of the stereographic projection and its early use in geology," *Terra Nova*, **8** (1996), no. 6, p. 499. • A. Hutchinson., "On a protractor for use in constructing stereographic and gnomonic projections on the sphere," *Mineralogical Magazine*, **15** (1908), p. 93-112. [Contains a history of projects from ancient times.] • W.H. Miller., "On the employment of the stereographic projection of the sphere in crystallography," *Philosophical Magazine*, **19** (1860), p. 325-328.



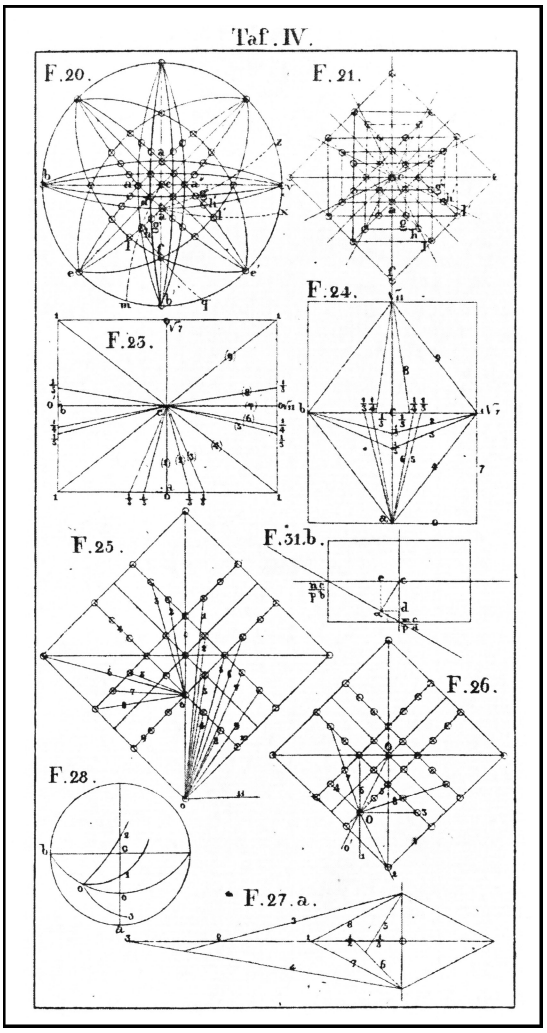
Sterographic Projection of Colemanite

Hipparchus about the middle of the second century b.c.e. It was used by Ptolemy later, about 150 b.c.e. in map making, and has been employed, more or less, until the present day. The projection, which is angle-true and which in all zones show great circles, is useful both for crystallographical and for optical work. It covers the hemisphere easily, but distorts polar angles increasingly as the margin of the hemisphere is approached.

In crystallography it was first used in 1823 by F. Neumann,[1600] whose book was apparently not appreciated, since only the first part was ever issued. Later, the method was employed extensively by William H. Miller who uses it to form the basis of his *Treatise on Crystallography* published in 1839.[1601] This is the same text in which the author gives his description of the system of facial indice notation that bear the name "Miller Indice" to the current day. In 1862, Des Cloizeaux employed it in his *Manuel de Minéralogie*, of which only a portion was ever published.

### Stereographic Nets

During the 1870s, it was realized that there was a need to better the determination of the optical properties of the feldspars in thin section as an aid to improving both the classification of igneous rocks and to gain a better understanding




First use of stereographic projection, 1823 (F.20)

of results obtained by experimental petrologists The earliest examples of polar and equatorial stereographic nets (6 cm diameter) appeared in 1892, in a publication bv the Russian crvstallographer Evgraf Stepanovich Fedorov (1853-1919) on the use of his universal goniometer an instrument he developed in the late 1880s for accurate measurement of the interfacial angles characterizing crystal forms (Fedorov, 1892) The 'universal' microscope stage, which he also invented (Fedorov, 1891), allowed a specimen to be inclined and/or rotated about any axis It was used to observe the effects of light passing through the crystal not solely in a direction normal to the plane of the slide, but also in any other required direction This enabled de-

[1600] F. Neumann., *Beitrage zur Krystallonomie*. Berlin und Posen, 1823.

[1601] W.H. Miller., *A treatise on crystallography*. Cambridge, 1839.

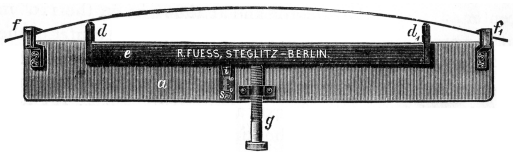
termination of diagnostic information on the nature of crystal and hence its composition His 'universal stage protractor' (Fedorov 1897) consisted of superimposed 20 cm diameter polar, E-W- and N-S-equatonal stereographic net1- and it was used to assist with the various corrections necessary to determine the orientation of the optical axis of a crystal It consequently became an invaluable aid to study of the optical properties of crystals in thin section His net was subsequently reproduced by Winchell (1937a) Polar stereographic nets were published by the Italian geologist Carlo Maria Viola (1855-1925) (Viola, 1898), who had studied under the crystallographers Paul Heinnch Ritter von Groth (1843-1927) and Victor Goldschmidt (1853-1933) in Berlin, and were also published in the United States by (Fisher, 1938) By the mid-1890s, use of both polar and equatonal stereographic nets as graphical aids to the study of feldspars had become relatively widespread (Fedorov, 1892, Michel Lev3/, 1894, Fedorov, 1897, Viola, 1898, Wulff, 1902) Particularly elegant examples are contained in a treatise by Michel Levy (1894) showing isohnes of common extinction/illumination and birefringence superimposed in colour on an equatorial stereographic net In America, Samuel Lewis Penfield (1856-190b) drew attention to use of the stereographic projection in geographical maps and navigational problems (Penfield, 1901a, Penfield, 1901b) and he subsequently published a 7-cm equatorial net for the mendians and parallels (Penfield, 1902a), and a second (17 cm) for parallels only (Penfield, 1902b).

The Russian mineralogist Georgn Yun Viktorovich Wulff (1863-1925), graduated from the University of Warsaw and subsequently studied under von Groth in 1890 before eventually taking up the position of Professor of Crystallography at Moscow State Universitv After using stereographic methods (Wulff, 1893), he published a 20 cm equatonal net with a 2 mesh (Wulff, 1902) This proved to be so useful that it was widely reproduced (Rosenbusch and Wulfing, 1904, Hutchmson, 1908, Berek, 1924, Winchell, 1937a, Fisher, l¡-¿38, Phillips, 1946, Phillips, 1954, Donn & Shimer, lc¿58) under the name of the Wulff net and is the most widely used equatorial sterographic net today Subsequently Rinne (1927) published a 17 5 cm net for a combined equatorial stereographic and gnomomc projection.

At the end of that century stereographic projection was much further developed by the invention of stereographic nets. In 1893, Benno Hecht included one of his own design in his *Anleitung zur Krystallberechnung.*[1602] Federov and Wulff also created nets, which will be discussed further along.

**Federov Net**

Slowly it became apparent to crystallographers that the tedious work of creating stereographic projections could be greatly simplified with the application of new tools. Protractors[1603] and various scales had been used for a long time in their construction, and since at least 1867 there was a large protractor divided by degrees of great and small circles used in the U.S. Hydrographic Office in preparation of navigation charts.[1604] In 1893, Wulff made sterographic projections to show the optical properties of several crystals. He included in the paper an illustration of a curved ruler he devised to help with drawing the arcs of the large and small circles.[1605]




Curved Ruler of Wulff and Federov

Beginning in 1893 in a series of articles, E. von Federov described various determininative methods used in mineralogy and petrology. He gave in the first paper a mathematical explanation of why the curve in the curved ruler is

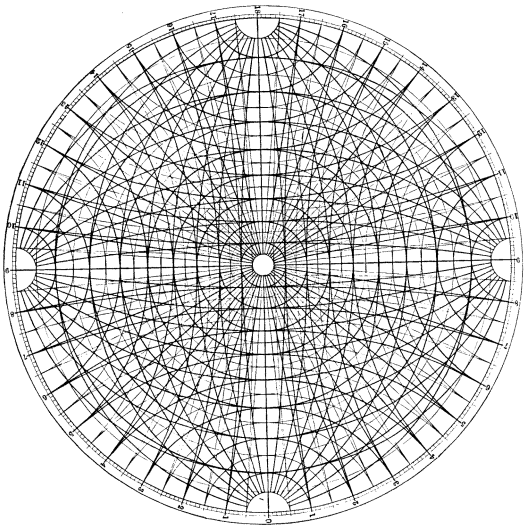
[1602] Benno Hecht., *Anleitung zur Krystallberechnung.* 1893. [Included a stereographic net of his own design that was about 10 cm. in diameter].

[1603] Alfred E. Tutton., *Crystallography*, 1922, **1**, p. 101-103.

[1604] C.D. Sigsbee., *Graphical methods for navigators.* U.S. Hydrographic Office. Washington, GPO, 1896. [An illustration is provided.]

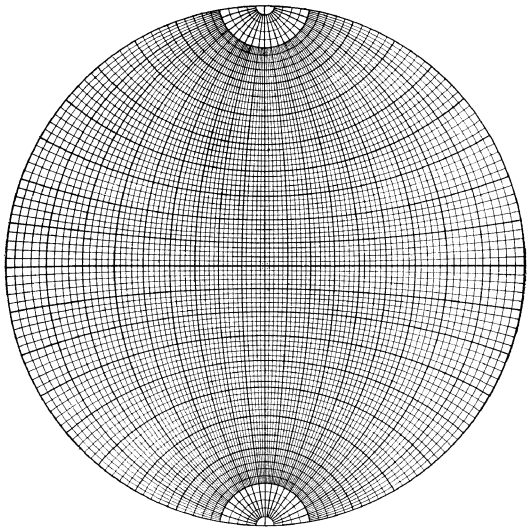
[1605] Georg Wulff., "Ueber die Vertauschung der Ebene der sterographiscen Projection und deren Anwendung," *Zeitschrift für Krystallographie*, **21** (1893), p. 249-254.

always the arc of a circle.[1606] From this proof he improved the "Curved Ruler" by the addition of a scale from which one can read directly the curvature of the arc.[1607] The insturment maker of R. Fuess Steglitz in Berlin seeing an opportunity apparently developed commercial copies of these rulers.[1608]



Federov Net

Federov continued to make breakthroughs to facilitate the creation of symmetry diagrams of crystals. He recognized that rather than starting from scratch each time, a prepared mesh showing the great and large circles separated by a set number of degrees could be used to help prepare the projections. In his paper of 1897, he published this stereographic net (known as the Federov Net) that greatly simplifies both drawing and computation of the projection.[1609] It was printed in pale blue or gray ink on tracing paper, and shows divisions, 5° apart, of two sets of stereographically projected great circles and vertical small circles at right angles to each other, one series of horizontal small circles, and one of vertical great circles, also 5° apart. The original diagram is 20 cm. in diameter, and was used by placing it over the drawing and pricking through to locate desired points, or by rotating it to read angles. A similar net was employed by Augusté Michel-Lévy in 1894.[1610] Immediately, the facility of these nets was apparent, and further development occurred.



Wulff Net

## Wulff Net[1611]

[1606] E. von Fedorow., "Universal-(Theodolith-)Methode in der Mineralogie und Petrographie. I. Universalgeometrische Untersuchungen," *Zeitschrift für Krystallographie*, **21** (1893), p. 574-714. • *ibid.*, "Universal-(Theodohth-)Methode in der Mineralogie und Petrographie. II. Krystalloptische Untersuchungen," *Zeitschrift für Krystallographie*, **22** (1894), p. 229-268. • *ibid.*, "Universalmethode und Feldspathstudien. I. Methodische Verfahren," *Zeitschrift für Krystallographie*, **26** (1896), p. 225-262. • *ibid.*, "Universalmethode und Felds pathstudien. II. Felds pathbestimmungen," *Zeitschrift für Krystallographie*, **27** (1897), p. 337-398. • *ibid.*, "Universalmethode und Felds pathstudien. III. Die Feldspathe des Bogoslowsk-scken Bergreviers," *Zeitschrift für Krystallographie*, **29** (1898), p. 604-658. • *ibid.*, "Universalgoniometer mit mehr als zwei Drehaxen und genaue graphische Rechnung," *Zeitschrift für Krystallographie*, **32** (1899), p. 468-478. • *ibid.*, "Zur Theorie der Kryslattographischen Proejctionen," *Zeitschrift für Krystallographie*, **33** (1900), p. 589-598.

[1607] E. von Fedorow., "Ueber die Anwendung des Dreispitzzirkels für krystallographische Zwecke," *Zeitschrift für Krystallographie*, **37** (1902-3), p. 138-142.

[1608] Alfred E. Tutton., *Crystallography*, 1922, **1**, p. 100-102.

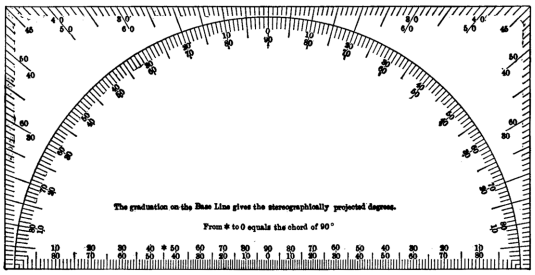
[1609] E. von Fedorov., "Universalmethode und Feldspathstudien. II. Feldspathbestimmungen," *Zeitschrift für Krystallographie*, **27** (1897), p. 337-398.

[1610] A. Michel-Levy., *Étude sur la détermination des feldspaths dans les plaques minces*. Paris, 1894.

[1611] G. Oittner-Torkar., "Die 'Wulffsche' Gleichung und der Beginn der Kristallstrukturanalyse," *Deutsches Museum, Wissenschaftliches Jahrbuch*, 1991, p. 176-188.

In 1902, Georg Wulff, in a very important paper on the optical properties of isomorphous crystals, published the lithograph net which because of its ease of use, is most commonly used to the present time.[1612] It is 20 cm. in diameter, but it is printed on heavy paper, and over it is laid the tracing paper on which the drawing is to be made. It shows the stereographic projections of great circles and of vertical small circles, 2° apart, and thus had more accuracy over Federov's net.

Other work was carried on in stereographic projection. Sommerfeldt extended the theory underlying the method beyond the boundary of the primitive circle,[1613] and Viktor Goldschmidt discussed the stereographic projection as regards its use for dealing with the data obtained by the use of the two-circle goniometer.[1614]




Protractor of Penfield

In 1901 appeared the first of a series of articles by Penfield on stereographic projection; a series which has done more than any other publication in English to bring the method before mineralogists and petrologists.[1615]

In his first paper, Penfield gave rather an elaborate discussion of principles and methods, and described a series of celluloid and paper protractors. His instruments and scales include (i) a protractor (Fig. 31) whose circle, 14 cm. in diameter, is divided into degrees, and whose base shows the stereographically projected positions of these points, (2) a protractor for measuring the arcs of great circles, and consisting of a series of vertical small circles 1° apart, (3) a protractor giving great circles and vertical small circles 5° apart, and (4) a protractor giving great circles 2° apart. Several of these protractors might well be combined into one, as is done is the Fedorow net.

Besides these protractors, Penfield made a series of very useful scales. One gives the radii of stereographically projected arcs of great circles, and is used to determine the centers of these circles in the projection without determining them graphically. Another gives the radii of stereographically projected arcs of vertical small circles, and a third gives the stereographic projections of the intersections of a vertical great circle with parallels, up to and including 156° from the north. The latter is a continuation of the base line of Fig. 31. A curved ruler, with the curved strip made of wood, thus dif-fering from the von Fedorow model mentioned above, is also described.

The name of Samuel Penfield stands out predominatingly, however, with regard to early twentieth century work on the stereographic projection. In a series of papers published in the *American Journal of Science*, Penfield has given a most exhaustive treatment of the subject, and published stereographic nets printed on transparent celluloid.[1616] Penfield also introduced sheets of paper on which are printed a circle of 14 cm. diameter divided into degrees, together with four scales: the first two give the radii of great and small circles respectively, the third is a scale of stereographically projected degrees, and the fourth is one the unit of which is the one-

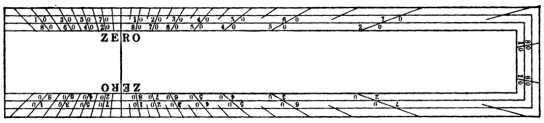
[1612] Georg Wulff., "Untersuchungen im Gebiete der optischen Eigenschaften isomorpher Krystalle," *Zeitschrift für Krystallographie*, **36** (1902), p. 1-28.

[1613] Sommerfeldt., "???," *Zeitschrift für Krystallographie*, **41** (1906), p. 164-???.

[1614] Viktor Goldschmidt., "???," *Zeitschrift für Krystallographie*, **30** (1899), p. 260-???.

[1615] Samuel L. Penfield., "The stereographic projection and its possibibles from a graphical standpoint," *American Journal of Science.*, **11** (1901), p. 1-24, 115-144. • *ibid.*, "On the use of the stereographic projection for geographical maps and sailing charts," *American Journal of Science.*, **13** (1902), p. 245-276, 347-376. • *ibid.*, "On the solution of problems in crystallography by means of graphical methods based upon spherical and plane trigonometry," *American Journal of Science.*, **14** (1902), p. 249-284.

[1616] Samuel Penfield., *American Journal of Science*, beginning with two in 1901 (ser. 4, vol. xi. pages 1 and 115), and including two important ones in vols. xiii. and xiv.




Protractor of Hutchinson

hundredth part of the radius.

Arthur Hutchinson [1866-1937] in a paper of 1908 discussees the construction of gnomonic and stereographic projections.[1617] He prepared a protractor and a net like the one just described except that it has a diameter of only 5 in. (12.6 cm.). For the use of students, and where extreme accuracy is not required, the 5-in. circle is much more convenient than the larger one, since it can be constructed on a sheet of paper of moderate size and most of its circles can be drawn with an ordinary pair of compasses. The protractor is adapted to the 5-in. circle. It is made of boxwood, is 2.5 in. in width, and about 12 in. in length. The intersection of the edge of the protractor with the zero line, which extends across it about 2 5/8 in. from one end, forms the center of the circle. The divisions toward the shorter end represent the stereographic projections of every second degree. The longer end is divided into degrees like an ordinary rectangular protractor and may be used for setting off angles. By multiplying these divisions by two it likewise gives the stereographic projections of points lying below the equator. For the sake of clearness, the finer divisions have been omitted from both ends in the figure.

## 14.8 Crystal Drawings[1618]

**REWORK:** A type of representation that conveys less exact information than either gnomic or stereographic projections about a crystals symmetry, but is more asthetically pleasing to the viewer is the crystal drawing. Like other projections of physical objects, drawings of crystals are only a representation, in this case of a crystal's corners and edges as if it were projected onto a definite plane. Found in many scientific works these drawings are not true perspective drawings because the parallelism of the edges of intersecting faces would be obscured. Instead, a crystal is drawn as if all the rays proceeding from the corners and edges to the eye were parallel. The crystal is, therefore, rendered much the same way it would appear, if it were placed at a very great distance and viewed through a telescope. To render the drawing the crystal is placed in front of the paper, so that one of its principal axes is placed vertically and parallel to the paper, while the eye is at a right angle. The lines, or rays, which join the eye to the edges are all parallel, and either (a) perpendicular to the paper, or (b) inclined to it at a fixed angle not varying much from 90°. The former case is the *orthographic* projection, while the later is called the *clinographic* projection.

Crystals can be represented by crystal-drawings, which give with sufficient accuracy the relative positions of the faces, those of the same form being usually equably developed. Drawings of crystals serve mainly to indicate their general habit, and aid us to distinguish the crystals of one substance from those of another: although, as already stated, the habit often varies greatly in crystals of the same substance; and, more especially, when they come from different localities, or are produced in the laboratory under different conditions. In drawings, irregularities in the size and shape of faces of a form are only admitted when they are needed to render manifest some peculiarity, either of general habit, or of a particular crystal. Drawings fail, however, to give that aid in the determination of symmetry which is afforded by the physical characters of the faces, for homologous faces on a crystal possess the same physical characters and show the same marks, such as striae, pittings, &c., which can only imperfectly be represented in drawings.

Drawings, which are orthogonal projections, may be divided into two classes : plans and elevations, described in section (i); and orthographic drawings, treated of in section (ii).

[1617] A. Hutchinson., "On a protractor for use in constructing stereographic and gnomonic projections on the sphere," *Mineralogical Magazine*, **15** (1908), p. 93-112. [Contains a history of projects from ancient times.]

[1618] Further historical information may be found in: L. Burmester., "Geschichtliche Entwicklung des kristallographischen Zeichnens und dessen Ausführung in schräger Projektion," *Zeitschrift für Kristallographie*, **57** (1922), p. 1-47. [Historical development of crystal drawing and projection.] • Alfred E. Tutton., *Crystallography*, 1922, **1**, p. 398-433.

In the former an important zone-axis, which may, or may not, be itself perpendicular to an important face, is placed at right angles to the paper. Strictly speaking, in a plan the vertical axis should be perpendicular to the paper, and in an elevation it should be parallel to the paper but we shall always speak of diagrams of both kinds as plans; and shall specify the face which is parallel to the paper, or the zone-axis and faces which are perpendicular to the paper. In orthographic drawings the important edges and faces of the crystal are inclined at some arbitrary angles to the paper. In clinographic drawings, treated of in section (iii), the vertical axis is in, or parallel to, the paper, but the crystal has in other respects an arbitrarily selected position with respect to the paper.

All the drawings of crystals which have been given in the foregoing illustrations have been constructed accurately to scale (the pencilled construction lines other than the crystal axes having been eliminated after inking in the outlines) on a conventional plan, the so-called clinometric or clinographic projection, a slightly inclined form of " parallel perspective," according to which the eye is supposed to be removed to an infinite distance, so that parallel lines, instead of converging to a vanishing point as in ordinary perspective, are actually parallel in the drawing. The general appearance of the crystal, as regards foreshortening from back to front, is at the same time very faithfully reproduced, which confers a great advantage over the isometric projection. The method is now universally employed, and is the accepted mode of drawing crystals for publication in the *Zeitschrift fur Krystallographie.*

The advantage will at once be obvious of a representation of a crystal on paper which, while correctly giving the impression taken in by the eye, assures that edges which are really parallel to each other shall still appear so in the drawing; for it is of the first importance to the detection and appreciation of the symmetry of a crystal to know which faces belong to the same zone, a fact which we have seen is indicated by the parallelism of their edges of intersection. Now the angle between the directions of two edges on different parts of a crystal is often so small that an inspection of a drawing in ordinary perspective would not inform us whether the edges were really parallel on the crystal or not, whereas on the plan adopted they are either parallel or not exactly according as they are drawn.

There is one further convention besides the parallelism of truly parallel lines and the back-to-front foreshortening, namely, that the eye is supposed to be raised somewhat above the horizontal plane, in order that something may be seen of the foreshortened upper faces of the crvstal from above, and also somewhat moved to the right, in order to see the right-hand foreshortened side faces. The standard position developed over a considerable time and implemented almost universally in the late nineteenth century is to draw the crystal as if it were rotated 18° 26' to the left and inclined 9° 28' forwards. The designation "clinometric " or "clinographic" refers to this fact, and distinguishes the method from the orthometric or orthogonal projection, which represents the crystal as seen directly from above, as in a plan, or from the front, as in an elevation, a plane of symmetry being usually the plane of projection.

In both the orthogonal and clinographic projections the light rays joining the eye and crystal coigns (solid angles, corners at which three or more edges meet) are all parallel, but in the former they are perpendicular to the plane of the paper on which the drawing is made, while in the latter they are inclined a few degrees out of the perpendicular to the paper.

The key to the whole drawing in clinographic projection is that of the crystallographic axes, which are first drawn in accordance with the rules of these conventions, and in agreement with the system of symmetry exhibited by the crystal. When once these are drawn, the crystal can be readily built up about them, for intercepts on these projected axes are proportional to the actual intercepts on the axes; and when the outline of the crystal is completed the axial scaffolding can be dispensed with, unless, as has frequently been the case in respect of the drawings in this book, it be considered desirable to indicate the positions of the axes by lines broken-and-dotted in order to distinguish them from the continuous lines indicating the front faces and from



On the History of Mineralogy & Crystallography from Beginnings through 1919
by Curtis P. Schuh, Tucson, AZ—Edit Draft. [1200dpi]
NOT FOR PUBLICATION Printed: September 18, 2007

the dotted lines indicating the back faces. The pencilled auxiliary construction lines, however, may be erased after the inking-in of the crystal outline and axes. The recent development of " process reproduction " by photo-engraving has rendered it usually most convenient for the purpose of subsequent reproduction, which requires an exceedingly clear and clean drawing, that the construction shall be done on Bristol-board, a fine-surfaced dense cardboard particularly suitable for such drawings in Indian ink. If the drawing be that of an original crystal, and the results of the investigation are to be published, it should be made twice or three times the size it is required to appear, in order that the engraver may reduce it to the required size during his photographic reproduction, and so greatly enhance the neatness.

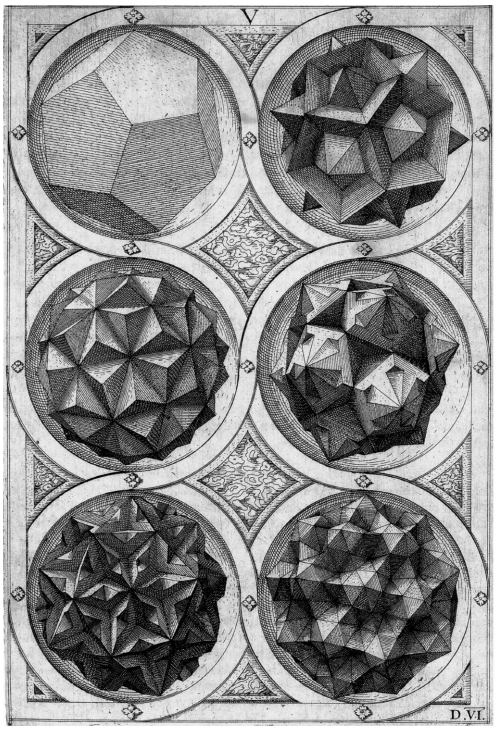
It must be remembered that the stereographic projection of a crystal - which will always have been drawn during the course of the measurements of the crystal angles and before the accurate drawing in clinographic projection is undertaken from the hand sketches of the crystal - is of the greatest help in constructing the clinographic projection. For it at once informs us which faces belong to any one and the same zone ; and as all such interfacial edges are parallel, and parallel lines remain as such in the clinographic projection, these edges must be drawn parallel to each other, wherever they appear unreplaced by other forms. Moreover, the general direction of any zone oblique to the axial planes, and its relation to other zones, will be clearly apparent on the stereographic projection, and will enable confirmation to be obtained of the accuracy of drawing of the interfacial edges of the zone on the clinographic projection. Indeed, it is possible to determine the directions of the interfacial edges of such zones by the graphical methods of Penfield,[1619] directly from the stereographic projection, when these directions are not already known by being parallel to the crystallographic axes. The student must, however, in any case be able to use the perfectly general and simple method of intersections described in this chapter, and can then with great advantage confirm the accuracy of the construction by reference to the stereographic projection.

Rules for constructing the Axes of a Cubic Crystal.-For all classes of crystals the axes have first to be constructed as for a cubic crystal, and then, when the latter is other than cubic, modified accordingly. Hence the construction of the cubic axes is of the first importance to the drawing of crystals, and it embodies all the various conventions which have been referred to. It is shown in Fig. 335, the method being the original one of Naumann, in the form recommended by von Grroth, and as it is usually employed for crystal drawings published in the *Zeitschrift fur Krystallographie*.

The projections of crystals are a means of conveying crystallographical information in a printed form. Stereographic and gnomic projections are useful to crystallographers for describing a crystal exactly; however, for the non-specialist, it is the beauty of a complex drawing that conveys the most information. In order to show the look of a crystal in the various publications, the techniques of crystal drawing was devised. Like the history of the science itself, the art of crystal representation developed over the course of centuries.

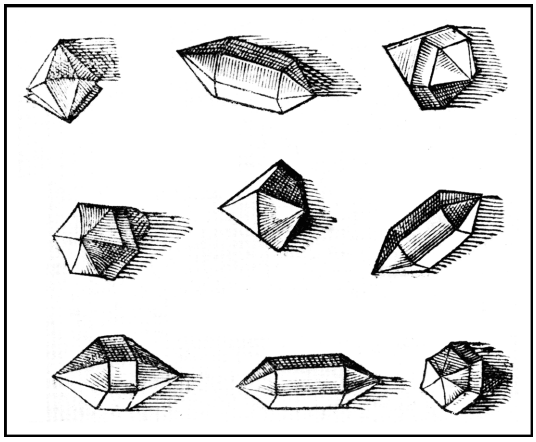
Wentzel Jamitzer [1508-1586] was a leading member of a German family of goldsmiths and engravers. In his *Perspectiva Corporum Regularium* of 1568 he illustrates many intricic geometric forms. These images are printed on the 51 double-page plates engraved by Jost Amman [1539-1591], but based on drawings supplied by Jamitzer. Developed in perspective over one hundred and forty simple and complex shapes from the geometric tetrahedron, octahedron, cube, dodecahedron and icosahedron by replacing all similar edges and angles by one or more planes are rendered. It is a early masterwork of geometric design, showing in the elaborate renderings solid bodies in shadowed silhouette so that they are given the illusion of three dimensionality on the flat page. In 1619, the famous astronomer Johannes Kepler developed mathematically a similar series of figures. Many of these shapes correspond to

[1619] Penfield, *Amer. Journ. of Science*, 1901, 11, 1 and 115; also 1902, 14, 249.




Jamitzer (1568)

crystals, and the method of modification may have suggested to others the method used by him in later centuries.



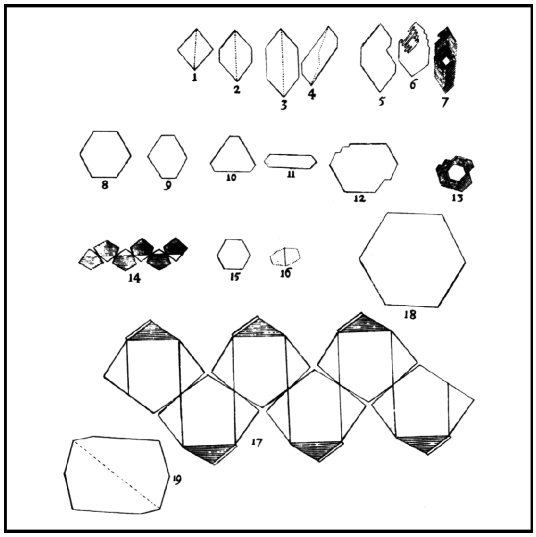
Boodt (1647)

Anselmus Boëtius de Boodt *Gemmarum et Lapidum Historia* (1647) *Gemmarvm et Lapidvm Historia* is one of the most important mineralogical works of the seventeenth century, marking a transition over previous lapidaries. It is of particular interest as a manual describing minerals that is more detailed, more extensive, more critical and more systematic than many earlier works. It was a well known and influential book, going through several editions and frequently being cited by other authors. A new era was marked with its publication. One in which the believes of the past began to be challenged, and the researchers began to use hypothesis and experimentation to present new ideas. Above all, Boodt's work is an early example of a treatise on mineral substances that departs from a simple alphabetical arrangement in persenting its description of stones.

The work is divided into two books. Book one presents several general considerations relating to the properties of minerals. In book two, the major portion, are discussed over one hundred different mineral substances. For each kind, Boodt records the various names by which it is known, physical properties, occurances, imitations, and the means of detecting imatations, uses emphasising medical prescriptions, and approximate cost. Contained within is an early attempt at the systematic description of minerals, with divisions of large and small, common and rare, soft and hard, flammable and nonflammable, transparent and opaque. Boodt notes the crystalline forms of some minerals as triangular, quadratic and heangular, and he provides critical references to earlier authors like Aristotle, Pliny and Parcaleus. Boodt was skeptical of the curative virtues of various gems. He suspected that it was coincindental that a specific type of gemstone was associated with a sick person who became well. Instead, he believed if stones had curative powers it was because they worked in concert with the body to affect a cure, not any supernatural property.

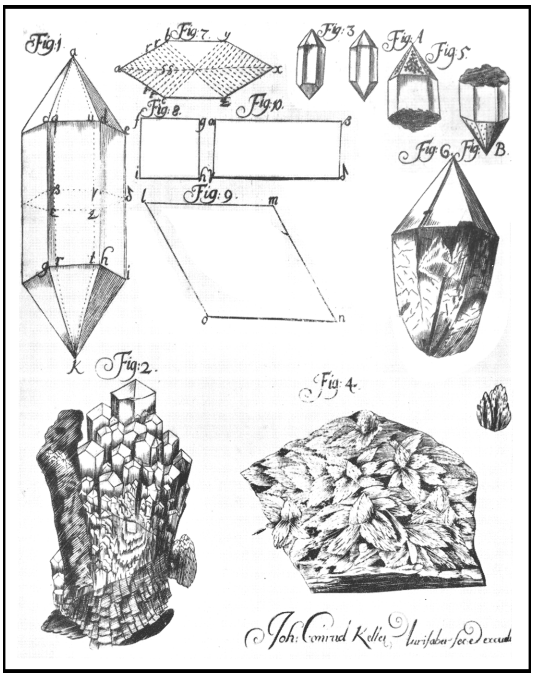
Discussing the properties of stones, Boodt gives a long discussion of hardness. He provides the earliest system of hardness grading for the various stones, which acted as a crude index to distinguish imatation gems from genuine. He distinguished three degrees of hardness and also included softness as a related but different property. Soft stones are considered such if fingers alone are sufficient to rub away the surface. Hard stones are called hard when they

can neither be rubbed away with fingers nor cut by iron. Hard stones are classified under three categories: (1) a steel file can scratch the stone, (2) only the use of the Smyrna stone [emerald??] can cut the surface, and (3) those that can only be rubbed away with a diamond point.



Steno's Diagrams of Quartz (1669)

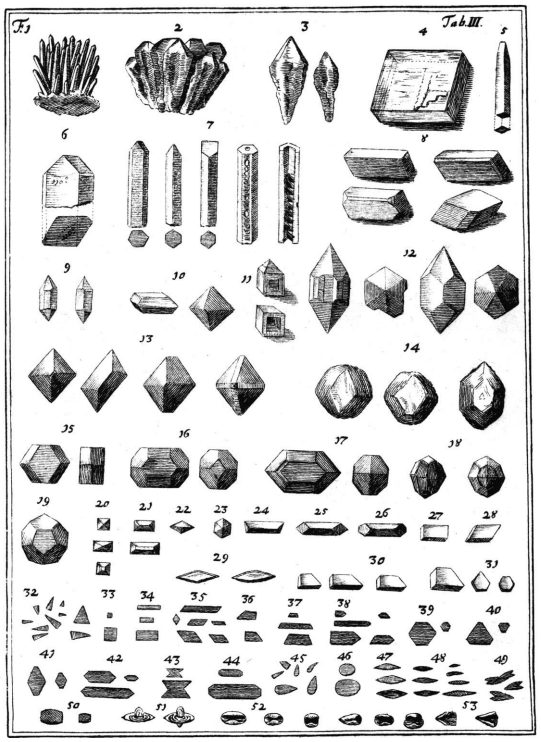
Nicolaus Steno in his notable *De Solido Intra Soldum Naturaliter Contento Dissertationis Prodromus* (1669) described various gems, minerals and petrifactions (fossils) enclosed within solid rocks. He compared the fossil with the living organisms, and distinguished marine and fiuviatile formations. He argued also in favour of the original horizontality of sedimentary deposits. But among his investigations were his other ideas the crystallization of quartz. The first investigation into the values of the dihedral angles of crystals was made by Nicolaus Steno, whose work was published in Florence in 1669. He cut a series of crystals of quartz of different habits in two directions at right angles to each other, (i) perpendicular to the edge, and (ii) perpendicular to one or other of the edges. By placing the sections on paper and drawing lines carefully parallel to the edges he was able to measure the Euclidean angle. In the first set of sections he found that all the angles between the faces m on the same crystal were equal to 120°, and that this was also the angle between similarly placed faces on other crystals. The normal-angle is therefore 60°. In the second series of sections he got figures which were not equiangular. Two of the angles at the vertices had the same value of 76° 26' in all cases; the four others had the same value of 141° 47'. He, therefore, inferred that in all crystals of quartz corresponding pairs of faces are inclined to one another at constant angles. His discovery that the interfacial angles of quartz crystals are always the same was an important discovery, and to illustrate this important concept, he illustrates on his plate cross sections of quartz crystals.



Hottinger (1698)

Hottinger *Die Krystallologia* (1698) At the age of 18, Johann Heinrich Hottinger authored and was respondent to this disseratation over which his uncle, Samuel Hottinger, presided. At the time, the Collegium Carolinum in Zurich was one of the great educational institutions of Europe, and it is perhaps through the influence of it famous professor, Johann Jacob Scheuchzer, that Hottinger was inspired to write this crystallography. In it, he gives a history and etymology of the term "crystal," classifies specimens according

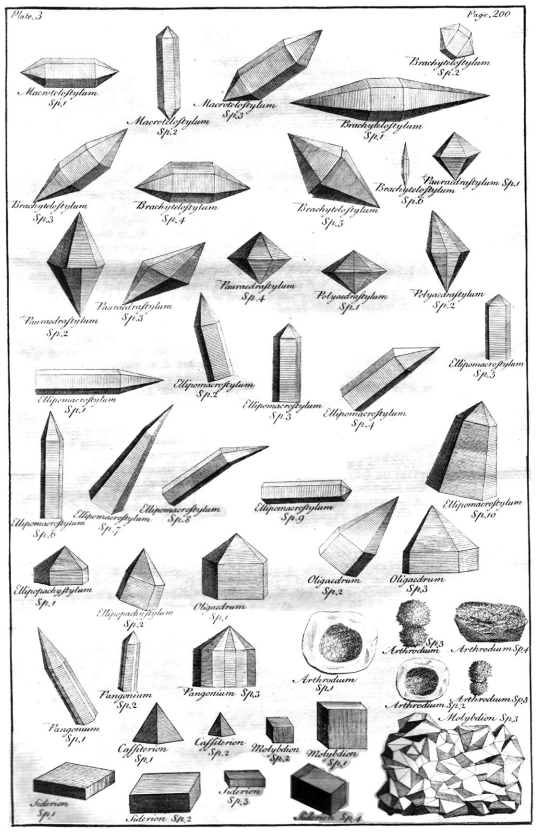
to external form, makes observations on crystal habit and concludes that crystals grew from solution. References are given throughout the text to contemporary literature.



Cappeller (1723)

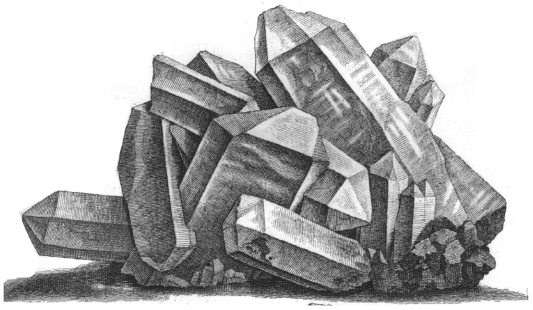
Moritz Anton Cappeller published his *Prodromus Crystallographiæ de Crystallis* in 1723. In this highly regarded crystallographic work, he examines a great variety of inorganic substances, sometimes employing a magnifying glass, Cappeller concluded that a small set of basic crystal forms existed. These he defined as the equivilent of dendritic, polyhedral, prismatic, pyramidal, rounded, cylinderical, boytroidal and crust-like. He illustrates these forms on the three plates, and believed that every crystal fell into one of these forms.

John Hill [c1707-1775] in his *Natural History of Fossils* of 1748 classifies the minerals into series, classes, orders, genra and the analog of species. They are then described according to their behavior in fire and acid, their cleavage or lack thereof, their surface texture, their appearance under the microscope, etc. Hill illustrates his text with a series of



Hill (1748)

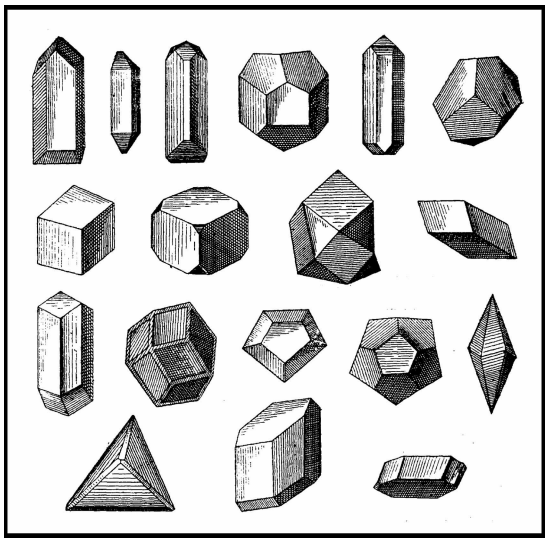
plates that includes two showing crystals of quartz, gypsum and calcite that are idealized representations of natural crystals.



Dezallier Quartz Specimen (1755)

In contrast, Antoine Joseph Dezallier d'Argenville [1680-1765] includes engravings of quartz specimens in his *L'Historie Naturelle Eclaircie dans une de ses Parties Principales, l'Oryctologie* of 1755. These are solid representations of the crystals as they would be found in nature, and are easily recogizable

to mineral collectors. In fact, they represent some of the best engraved mineral illustrations executed in the eighteenth century.

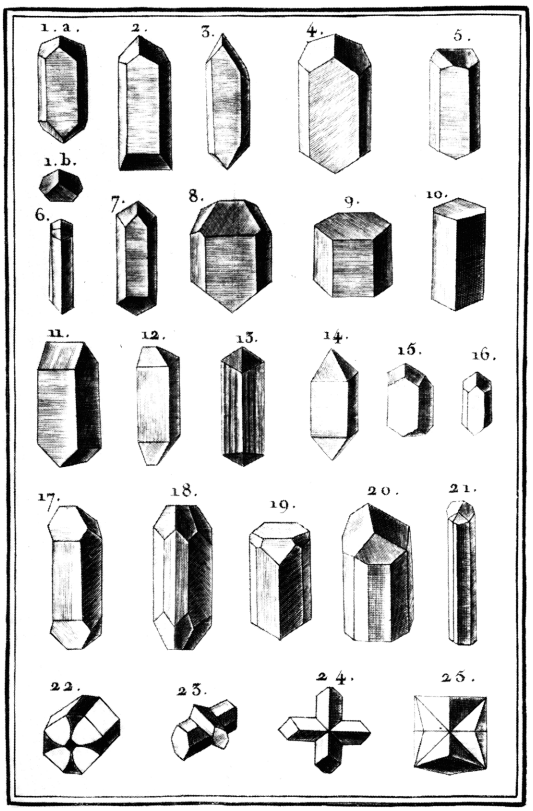


Linneaus (1768)

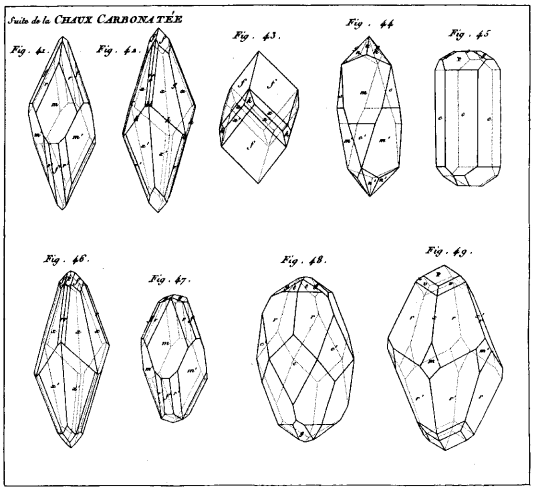
Linneaus attempted to give the allusion of a crystals three dimensional form by the use of diagram shading. His works in natural history were all very influential and widely read.

In his *Cristallographie* (1783), Romé de l'Isle also used shading to give a three dimensional allusion to the crystal shapes he illustrates. Ancillary evidence suggests that the plates were engraved after crystal forms carved from either alabaster or brass. The requisit crystal angles on the models having been measured with the recently invented contact goniometer.

By 1801, in the hundreds of crystal diagrams depicted in Haüy's *Traité de Minéralogie* the dimensionality is captured by using dashed lines to indicate the hidden faces, if the actual crystal were in front of the viewer. This type of diagram conveys to the viewer a great deal about the crystal shape, and actually is perhaps better than the shading effects of the previous works. It quickly became a standard type of crystal illustration and was copied in later works such as Robert Jameson's *System of Mineralogy* (1816) and



Romé de L'Isle (1783)



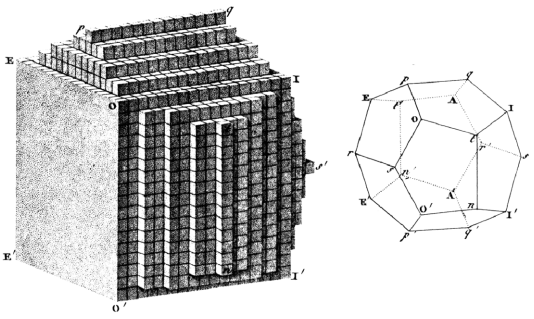
Haüy (1801)

Parker Cleaveland's *Elementary Treatise on Mineralogy and Geology* (1822).

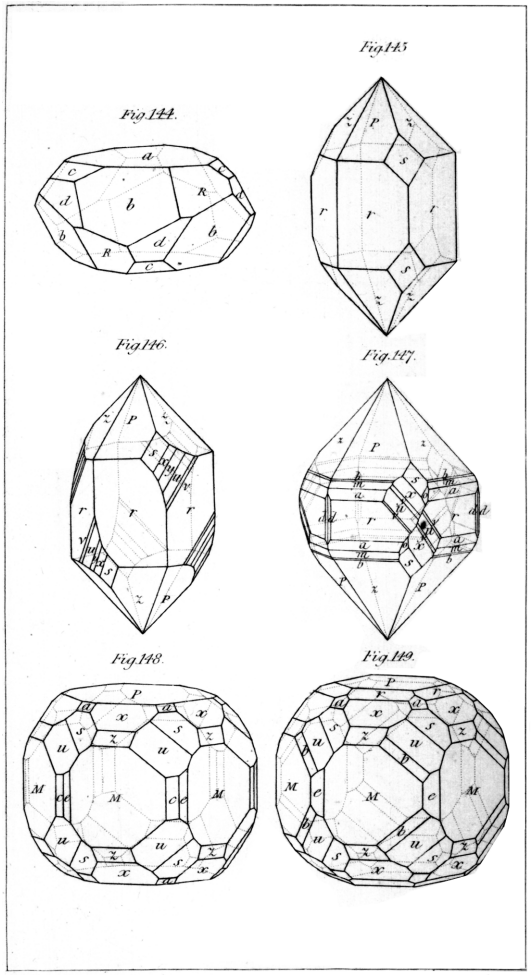
Haüy also used his crystal illustrations to show how his crystals were built from the "molecule integral". These famous diagrams have often been reprinted and show Haüy's



On the History of Mineralogy & Crystallography from Beginnings through 1919
by Curtis P. Schuh, Tucson, AZ—Edit Draft. [1200dpi]
NOT FOR PUBLICATION Printed: September 18, 2007



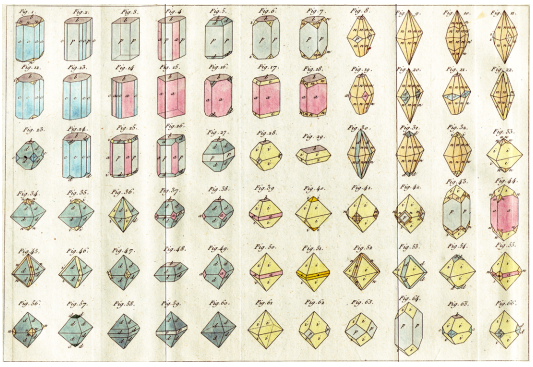
Haüy Structural Diagram (1801)




Haidinger-Mohs (1825)

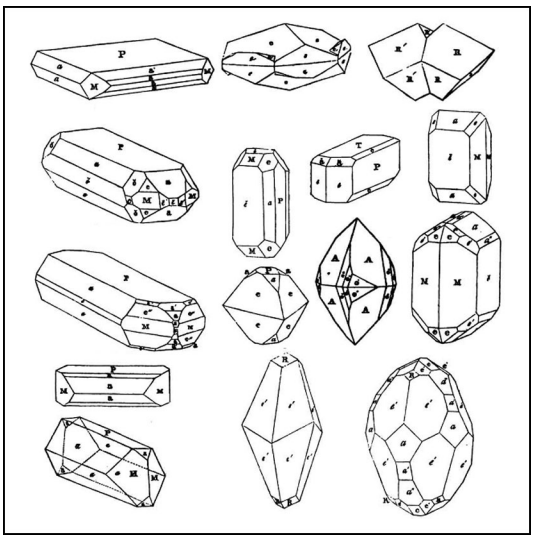
theoretical structure inside the crystal.

In 1825, Haidinger in his English translation of Friedrich Mohs *Grundriss der Mineralogie* (1822) follows the led of Haüy and uses dashed lines to indicate hidden faces in his crystal drawings. He also wrote an article on how to prepare drawings of crystals.[1620]



Beudant (1832)

Beudant attempted to distinquish primary and secondary forms of crystal in his drawings. In some copies of the second edition of his *Traité de Mineralogie* (1832), the crystallographic plates of the first volume that show the seven crystal classes have been carefully hand colored in pastels to contrast primary and secondary crystal forms on the diagrams.



Dana (1837)

James Dwight Dana, wrote in 1837 at the age of 24 the first edition of perhaps the single most significant contribution to American mineralogy, *The System of*

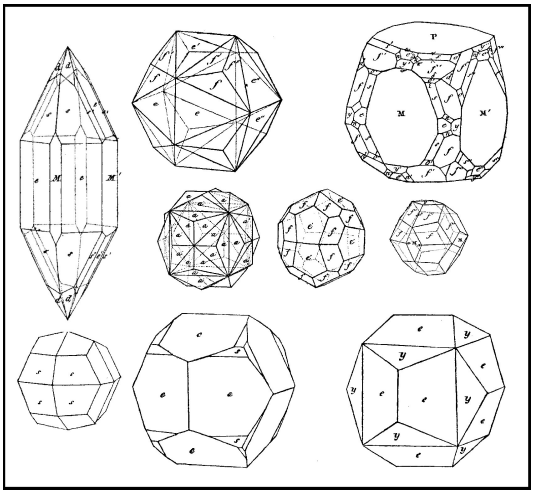
[1620] Wilhelm Haidinger., "On drawing crystals in true prespective," *Memoires of the Wernerian Society*, 1822-23, p. ??-??.

*Mineralogy*. Benjamin Silliman reviewing the work, wrote: "On the whole, we believe this to be decidedly among the best treatises upon this subject that have ever been circulated in the United States, and we are of the opinion that even a slight examination of it, will be sufficient to commend it to the favor of every cultivator and lover of mineralogy." The text is a very complete and readable compendium of all mineralogical data available to that time. Thus this book is a fitting first entry into an extraordinary publishing history that would see the *System's* third edition of 1850 define modern systematic mineralogy and see the *System's* sixth edition of 1892 become arguably the greatest mineralogy ever published as a single volume.

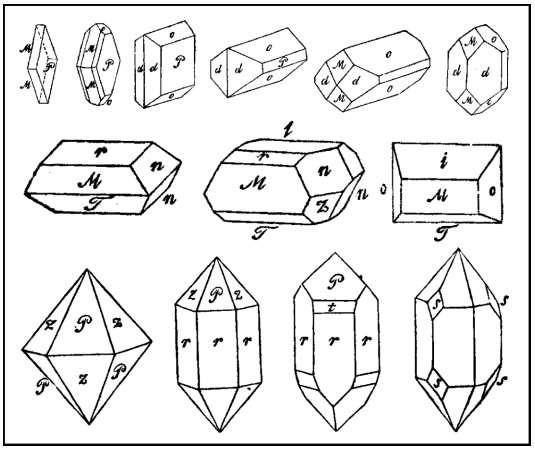
Dana illustrated his text with over 250 woodcut crystal figures that are peppered throughout the volume and on the four copper engraved plates included at the end. He had drawn all of these figures by hand, and through practice developed an appreciation for the art to creating a good illustration. He collected together his thoughts and techniques on crystal drawing and published an article on the subject.[1621] Over fifteen years later, he wrote another paper on the best method for lettering the faces of the crystal drawing.[1622]

Naumann (*Lehrbuch der Krystallographie*, II., p. 400 et seq., 1830), projected a set of rectangular axes of equal length in the following way. One face of a cube is first placed in the paper with one of its edges vertical. The cube is then turned about one of the vertical edges, lying in the paper, through an angle p, so that the width of the face to the left is n times that to the right. So far the construction is the same as that of Mohs given in Art. 9. If the paper be turned through 90° until it coincides with the horizontal plane, OA and OB are two of the axes, and their projections on the horizontal line of the drawing are given by OD and OE of Fig. 58.

Naumann now supposed the eye to be raised above the horizontal plane so as to look down upon the top of the cube. The vertical axis is unaltered in length and position, for it is in the paper. Crystal drawings of this type are very pleasing to look at and are the most widely type of drawing done to represent a crystal form. It is called the *Clinographic Drawings* because of its perspective.



Naumann (1830)



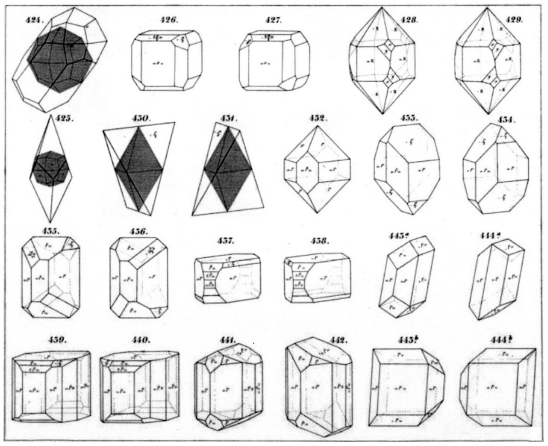
Naumann (1846)

The very popular *Elemente der Mineralogie* of Carl Naumann was a textbook used in Germany and elsewhere. Each one of its many editions always included hundreds of crystal drawings to illustrate the forms exhibited in the species it describes. In the first edition of 1846, these diagrams were small woodcuts of crystals with faces lettered with Naumann's symbols in

[1621] James D. Dana., "On drawings figures of crystals," *American Journal of Science*, **33** (1838), p. 30-50.

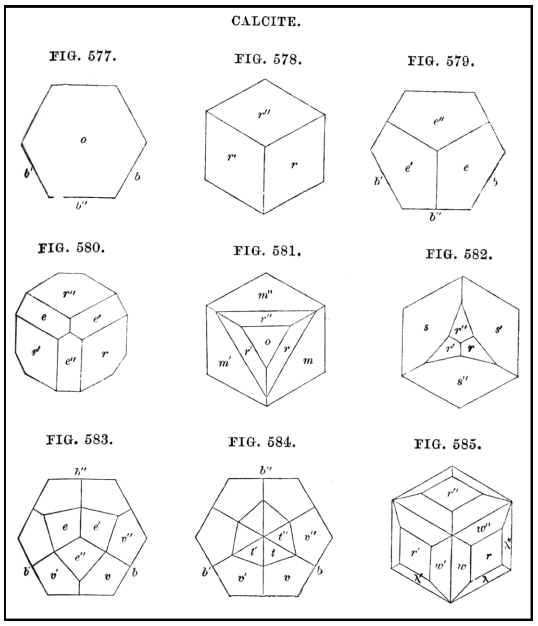
[1622] James D. Dana., "On lettering figures of crystals," *American Journal of Science*, 2nd Series, **13** (1852), p. 399-404.

a perspective view. By the 18—— edition, the woods cuts were replaced by copper engraved diagrams that followed the same format.



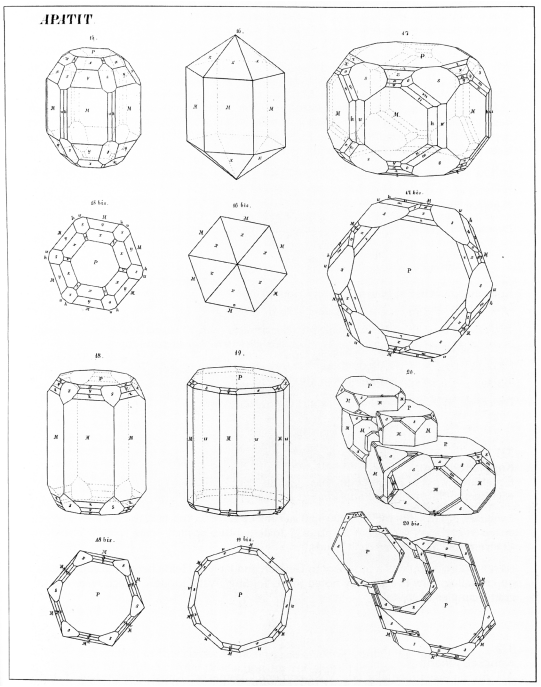
Kopp (1849)

Hermann Franz Moritz Kopp's *Einleitung in die Krystallographie* (1849) Kopp a German chemist at the University of Heidelberg, is best known for his work on physical chemistry and crystallography and publications on the history of chemistry. His introductory mathematical treatise of crystallography for students of chemistry and mineralogy was first published in 1849 and is considered a classic.




Phillips (1852)

Figures of *Plans and Elevations* are largely used in Brooke and Miller's edition of Phillips's *Mineralogy*, 1852. The drawings are easily executed, and give a fair idea of the end of the crystal directed towards the observer. They, however, fail to render sensible the inclination of the faces and edges to the line of sight, and they are deficient in the appearance of solidity. In the 1852 *Elementary Introduction to Mineralogy*, Brooke and Miller use mostly orthogonal views to illustrate their crystals. This was an important text book of the mid-nineteenth century, and its influence was great.

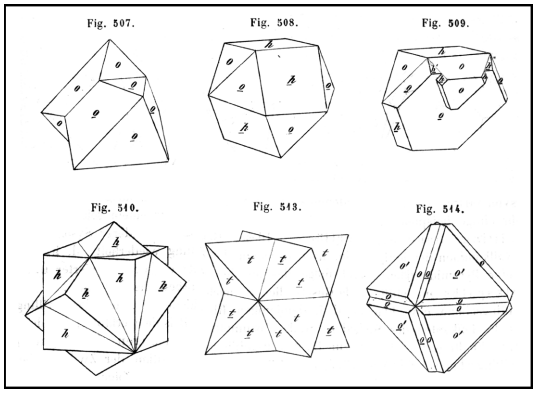



Koksharov (1853)

The Russian crystallographer, Koksharov was one of the outstanding drawers of crystals during the ninteenth century. He appears to have purpousely selected his material base on the complexity of the forms, and his drawings are almost always some of the most beautiful drawings ever made.

By the later portions of the nineteenth century, new printing techniques allowed for the inclusion of high quality crystal drawings at a reasonable price. Dana's *System of Mineralogy* and other books of the period benefited from this practice. However, depending on the

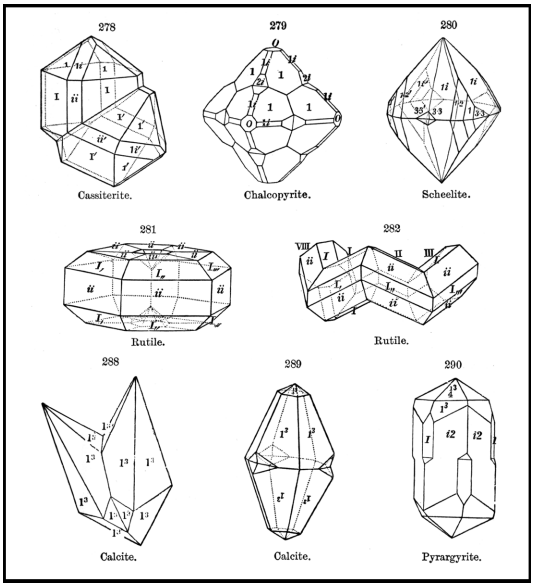
publisher and the author, the quality varied greatly from publication to publication. For cheaper books, wood cuts were still the preferred method for creating the illustrative crystal drawing, while in the more elaborate texts, copper, steel, and finally photographic methods, were used to insert the desired rendering.




Groth (1876)

In 1876, Paul von Groth published the first edition of his *Krystallographie*, which was quickly recognized as a work of quality and throughness. It went through four editions to 1905, with each edition containing outstanding crystal drawings, a study that Groth appears to have been especially interesting. In 1877, a year after the first edition appeared, Groth founded the scientific journal *Zeitschrift für Krystallographie* that continues to published today. This journal soon became one of the principal periodicals for the professional crystallographer and mineralogist to publish their papers. As a consequence of the material published, many thousands of crystal drawings were included in its pages. A standard format was prepared so that all crystal drawings would have a consistant look.

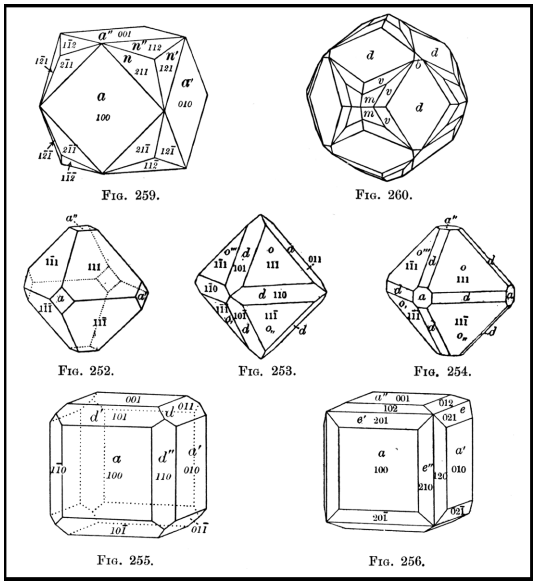
The standard position, as afforded by the construction rules given exhibits the crystal as if it were rotated 18° 26' to the left and inclined 9° 28' forwards. The designation "clinometric " or "clinographic" refers to this fact, and distinguishes the method used from the orthometric or orthogonal projection, which represents the crystal as seen directly from above, as in a plan, or from the front, as in an elevation, a plane of symmetry being usually the plane of projection. The stature of the *Zeitschrift für Krystallographie* was such that their format for crystal drawings quickly became the standard for all works of crystallography and mineralogy, and it is a standard still followed to the present day. Soon, authors included sections in their textbooks describing how to prepare the appropiate crystal drawings, or wrote articles explaining the techniques of drawing crystals.




Dana (1877)

In the *Textbook of Mineralogy* written by Edward S. Dana in 1877, this work was executed with the science student in mind. One half of the text is occupied with descriptions of crystallography, physical, chemical and determinative mineralogy, while the other half contains the descriptions of species and a catalogue of American mineral localities. The subjects of crystallography and optical mineralogy are treated at length so that the student may acquire the special knowledge needed for complete mineral investigations. For this section fine illustrations and descriptions of the best instruments are given, as well as numerous diagrams and figures of crystals. Descriptive crystallography is covered with sections concerning mathematical crystallography following the systems of Nauman and Miller's. Each of these

subjects is also very fully illustrated by figures. In addition, a chapter covering the optical characters of minerals, is among the finest treatments ever printed in the English language. Besides there is a bibliography of the subjects considered under physical mineralogy. Appendix B is "On the Drawings of the Figures of Crystals."

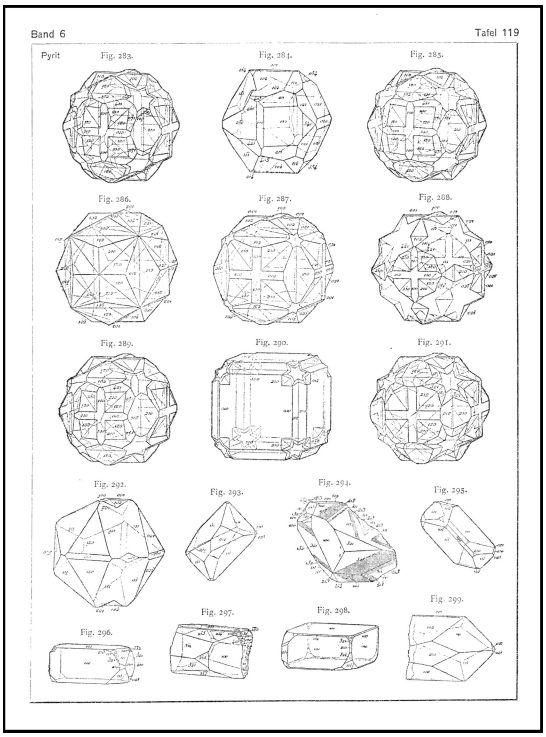



Lewis (1899)

By the end of the nineteenth century, many of the textbooks had chapters describing the procedures for drawing crystals. In 1899, William James Lewis issued his *Treatise on Crystallography*. This highly esteemed work, that gives a clear lucid explanation of its subject, treats crystals, their origins, law of interfacial angle constancy, symmetry, axes, zones, crystallographic projection, twins, crystallographic systems, etc. One particularly good section pertinent to the discussion is contained in chapter six, "Crystal Drawings." Lewis describes the techniques employed to render crystal forms in two dimensions. The work is illustrated with numerous diagrams of good quality.

Penfield wrote a series of important articles on representing crystals through projection and drawings.[1623]

[1623] Penfield., "On Crystal drawing," *American Journal of Science*, **19** (1905), p. 39-??. • *ibid.*, "???," *American Journal of Science*, **21** (1906), p. 206-??.




Goldschmidt (1913)

Beginning in 1913, Victor Goldschmidt began publishing the monumental *Atlas der Krystallformen*. The encyclopedia of crystal morphology, whose purpose was to collect, index and reproduce in one work all the crystal forms observed for every mineral species. In 1913, a *Prospectus* for this work consisting of 8 pages of text and 8 plates was given a lengthy notice in the *American Journal of Science* [See: *4th Series*, **35**, 553]. After reminding the readers that a previous attempt by Albrecht Schrauf to publish such an atlas had collasped after only a single volume had appeared, the review goes on: "... the work will embrace from 25,000 to 28,000 figures; these will be included in five or six volumes of about 250 plates each, with a like number of volumes of text." One wonders if the readers of this notice actually expected to see Goldschmidt's *Atlas* to be completed. Most probably did not realize this was the keystone to the author's crystallographic work. With the *Index der Krystallformen der Mineralien* (3 vols., Berlin, 1886–91) and *Kristallographische Winkeltabellen* (Berlin, 1897), it forms the

last segment of a trilology Goldschmidt had intended to publish from the start of his carrer, and which incidently defined modern crystal morphological studies. In the preface to the text, Goldschmidt explains the broad standpoint that has led him to develop this work. His desire was to bring together the material necessary for solving many of the problems of crystals and their growth, particularly with respect to habit, the frequency of occurrence of certain forms and the relative size of the faces. The tremendous depth of the work is astonishing, with most mineral species represented by several hundred to a few thousand crystal drawings. The reproduction of these figures is excellent as well. Goldschmidt did not attempt to redraw each of these figures as Schrauf had done. Instead original figures were reproduced by the printer using photographic techniques onto the zinc plates used for printing. This enabled Goldschmidt to size, adjust and rotate the original drawings as needed. The text is arranged alphabetically by mineral name, and consists of two parts. The first and most important of these are the plates, for they create the esthetic value of the work. Reproductions of many thousands of crystal drawings illustrate graphically all the variations in form observed for every mineral. Supporting these figures is the text, which lists the various characteristics of the minerals, and gives a detailed accounting of the locality and exact reference sources for each figure pictured.

## 14.9 Crystal Models[1624]

Another type of crystallographic projection that was a great aid in the study of natural crystals, were perfect, idealized models of crystals. Since perhaps as early as the seventeenth century models were constructed out of plaster and wood. The Danish geologist Nicolaus Steno may have constructed models of quartz crystals to verify his revolutionary concept that the interfacial angles were always the same. However, the earliest citation of using models in connection with mineralogy occurs in Linneaus' writings where the great Swedish naturalist prepared crystal models of wood perhaps as early as 1735.[1625] In a letter from Linneaus to the Swedish physician Abraham Bäck [1713-1795] dated 4 February 1773 he indicates that incorporated into his mineral collection idealized crystal models of wood that had been manufactured by Tidström.[1626] But it was not until a half century later that crystal models would become a tool widely used in crystallographic studies.

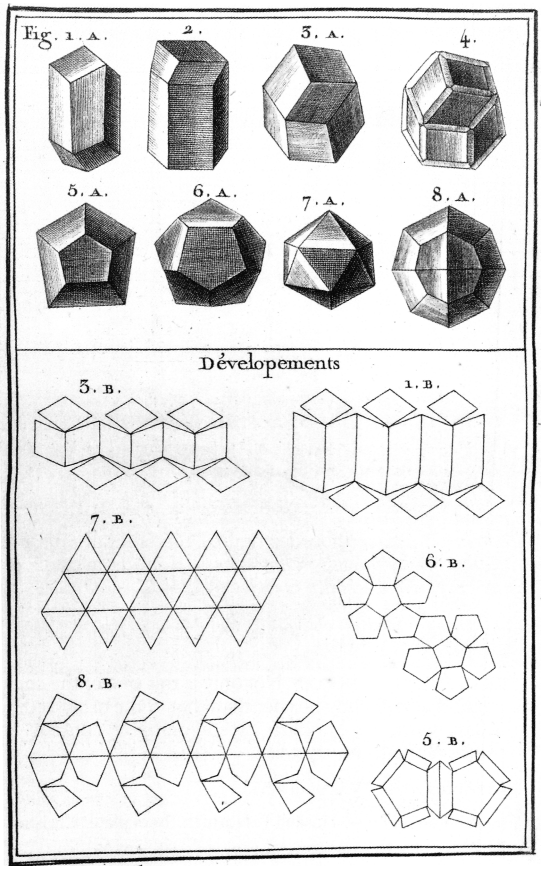
In 1772, Romé de L'Isle published the first edition of his famous *Essai de Cristallographie*, which emphasized physical characteristics to define crystallography and mineralogy as a science. He includes plates illustrating various crystal shapes that in some instances he has also included, what he calls "Dévelopements." These are the same crystal shapes that if the faces were unfolded would look like these line drawings. If these drawings were drawn on new paper, cut out and folded along the lines, they would fold into a three dimensional crystal shape. It is not clear from the text if Romé's "Dévelopements," were intended to be used as the first publication of paper crystal models. The first edition of Romé's *Cristallographie* was a successful work, and its reception encouraged him to prepare a second much enlarged edition that included 483 illustration of mineral crystals from his personal collection. He further commissioned the engraver Swebach-Desfontaines to create copies of each of these crystals in terra-cotta to be sent as a premium to subscribers to his second edition.

Swebach requested for an initial set of clay models from which to work to prepare the crystal sets. These original clay models

[1624] Further historical information may be found in: Rudolf Biedermann, ed., *Bericht über die Ausstellung wissenschaftlicher Apparate im South Kensington Museum, zu London, 1876.* London, 1877. xlvi, 1061 p. [A description of all of the instruments contained in the British Museum collections, encompassing in mineralogy, crystal models, goniometers, blowpipes, etc.] • Leopold Josef Fitzinger., "Geschichte des k.k. Hof-Naturalien-Cabinetes in Wien," *Sitzungsberichte der kaiserlichen Akademie der Wissenschaften. Mathematisch-Naturwissenschaftliche Klasse*, **28** (1881), p. 279-342. [Contains much information about their crystal model collections.]

[1625] F. De Jong and E.Strander., "Skizze der Entwicklung der geometrischen Kristallographie und den Struturtheorie," *Geologische Runschau*, **5** (1955), no. 4, 362-79.

[1626] H. Sjögren., *Carl von Linné als Mineralog*, Jena, 1909, p. 17.




Romé de l'Isle, 1772, plate 8

were perhaps then rendered in more sturdy alabaster examples so that molds could be made to produce the hollow terra-cotta sets sent to subscribers. So Romé de L'Isle hired his students Arnould Carangeot[1627] and Claude Lemina to fabricate them. Carangeot in particular had difficulty in measuring the interfacial angles of a quartz crystal. After some frustration in attempting to complete the task, Carangeot struck upon the idea of constructing templates with which to carve the clay at the correct angles. Later he refined the templates so that any general angle could be constructed or measured, and thus the first contact goniometer was invented (see § ).

Unfortunately the terra-cotta crystal sets supplied by Romé de L'Isle with his *Cristallographie* were apparently rarely made and perhaps to brittle to have easily survived from the eighteenth century. Yet one set preserved in a royal collection since they were issued was auctioned off with many books of mineralogical interest in July, 1982. Lot 230 of the catalog which eventually became part of the British Museum's collection was described as follows:

> Romé de L'Isle, (J.B.L. de). A set of modern crystals to illustrate Romé's important work on crystal forms and the constancy of interfacial angels, comprising: 177 crystals (a few missing) contained in 4 book-type calf boxes with 23 cabinet drawers, lined in blue silk and onlaid with gilt wire, spines of boxed detached and some slight overall damage, but a remarkably intact set. 8vo. [Paris, c1783].[1628]

Paris became the early manufacturing center for crystal models and René Just Haüy's *Traité de Mineralogie* published in 1801 was the basis for many crystallographic models. Wooden models were prepared by Claude Pleuvin who was located at the Jardin des Plantes in Paris. A complete set of the Haüy models was said to contain more than 600 examples.[1629] These wooden crystal models were popular tools among collectors and museums throughout Europe. In 1797 the Danish collector Greger Wad purchased a collection of Romé de L'Isle's models and in April 1800 Haüy's model collection was secured. These suites became part of Count J.G. Moltke's [1746-1818] mineral collection when he acquired Wad's cabinet. The remnants are today probably in the Geologisk Museum at the University of Copenhagen when they acquired Moltke's collections in 1810.[1630] In

[1627] Arnould Carangeot (born: Rheims, France, 12 March 1742; died: Meaux, France, 18 November 1806) studied in Paris and became interested in the natural sciences. His integrity won him several patrons that allowed him to study mineralogy, botany and entomology. As an entomologist, Carangeot authored the text of volumes IV-VII (1785-93) of d'Orcy's *Papillons d'Europe peints d'après nature*. [*DSB*, **3**, p. 61-62.]

[1628] Sotheby Parke Bernet & Co., London. *Catalog of Printed Books. The Property of a Nobleman (von Fürstenberg family)*. July, 1982.

[1629] J.G. Schneider., "Die Mineralien-Sammlungen in Paris," *Leonard's Taschenbuch*, **1** (1807), p. 221-222. • A. Birembaut., "L'Enseignement de la minéralogie et des techniques minières," (pp. 365-418; see page 394) in: René Taton., *Enseignement et diffusion des sciences en France au XVIIIe siècle*. Paris, Hermann, 1964.

[1630] A. Garboe., *Geologiens historie i Danmark*, Copenhagen, 1959, **1**, p. 176-177. • U. Burchard., *Mineral museums of Europe*, p. 64.

1802 a complete set of Haüy's wooden crystal models was purchased by the Teylers Museum in Haarlem of The Netherlands where they still are contained in the collection together with the original invoice.[1631] Elsewhere in Paris, a dealer in natural history objects including minerals by the name of Lambotin had a shop located on St. Germain was said to have for sell crystal models made of porcelain that were said to be externally exact. Lambotin's set contained 27 examples and contained all the crystals depicted on the plates contained in Jean-André-Henri Lucas' *Tableau Méthodique des Espèces Minérales* published in Paris in 1806.[1632]

Outside of France other suppliers of crystal models made from paper, plaster or box wood began to appear. In Germany, Karl Immanuel Löscher[1633] published in 1796 his *Uebergangs-Ordnung bei der Kristallisation der Fossilien, wie sie aus einander Entspringen und in einander übergehen.* This rare book could be purchased with or without an accompanying set of wooden(?) models that would provide the reader with a true hands-on feel for crsytallography.[1634] Recognizing the need to provide a reader with the ability to view crystal forms in three dimensions, Carl Constantin Haberle published the *Sammlung von Krystall-Modellen zur anschaulichen Erläuterung der Grundgestalten, Hauptkerngestalten und Hauptkrystallgestalten der Mineralien so wie auch der Verhältnisse, welche man unter Abstumpfungen, Zuschärfungen und Zuspitzungen begreift für Anfänger im Studium der Mineralogie* (Weimar, 1805). After a short introduction, Haberle provides the first known example of cut apart paper diagrams for 106 crystal forms that when separated, folded and glued, provided a physical model to study the idealized crystal. However this innovation was not immediately followed by other suppliers. In August, 1813, Carl Heinrich Titius was offering for 32 German Thaler a set of wooden crystal models prepared in Freiberg by Löscher under Abraham Gottlob Werner's supervision and organized along Werner's classification.[1635]

In England, James Sowerby who had recently become an active mineral enthusiast prepared one of his very rarest publications in a short lived attempt to supply to the public basic information on crystallography using simple crystal models. He prepared his *Part I. (Price 1s. alone–With the Models 10s. 6d.) Of a Description of Models to explain Crystallography; or, an easy introduction to the understanding of the formation of crystals, so essential to the knowledge of all substances, chemical or mineralogical* (London, R. Taylor, 1805). Sowerby wrote his intentions in publishing the work:

> "Deeply impressed with the idea of the importance of crystallography, I have resolved, with a view to facilitate its study, to prepare models to contain the modifications of the crystals of the different substances, enclosed in boxes, which will generally show the primitive form of the particular substance to which they respectively relate; each box or part will be accompanied with a printed description or explanation of the several modifications; and the whole will consist of eight or ten parts." [1636]

Although Sowerby indicates that the next installments of the series will cover sulphur and diamond "chiefly explained by models made of the best cut glass,"[1637] the only section apparently ever published is the first installment that is a description of Newcastle coal with a model made from ebony and boxwood. This was an odd choice, since coal does not form crystals!

Sowerby's other more successful mineralogical publications such as *British Mineralogy* helped contribute to the public's interest in mineralogical and crystallographic studies in England during the first decades of the nineteenth century. With this interest came an

[1631] U. Burchard., *Mineral museums of Europe*, 1986, p. 168.

[1632] J.G. Schneider., "Die Mineralien-Sammlungen in Paris," *Leonard's Taschenbuch*, **1** (1807), p. 221-222.

[1633] Karl Immanuel Löscher (born: 27 July, 1750 at Wiederau, Saxony, Germany; died: 21 March, 1814) was the royal mine supervisor at Clösterle in Boehmia. Later he lived in Freiberg, where he became acquainted with Werner.

[1634] C.M. Marx., *Geschichte der Crystallkunde*, Carlsruhe, 1825, p. 114.

[1635] W. Fischer, *Mineralogie in Sachsen von Agricola bis Werner*, Dresden, 1939, p. 181.

[1636] J. Sowerby, *Of a Description of Models*, 1805, p. 6.

[1637] J. Sowerby, *Of a Description of Models*, 1805, p. 7.

opportunity for an enterprising German immigrant to supply Great Britain with all manner of mineralogical instruments and tools including crystal models. Following the earlier example of Löscher, Frederick Accum sold his book *Elements of Crystallography, after the Method of Haüy; with, or without, Series of Geometrical Models, both Solid and Dissected; Exhibiting the Forms of Crystals, their Geometrical Structure, Dissections, and General Laws. According to which the Immense Variety of Actually Existing Crystals are Produced* (London, 1813) with or without a series of wooden crystal models. In a notice published in Nicolson's *Journal* about 1813 Accum describes his intentions:

"I would like to submit to your consideration, Sir, that he who establishes a place of fabrication or deposit of an article of use to the sciences, which could not before be purchased, is a benefactor to the public; and under this point of view I offer you the present notice, as a piece of scientific news, though it is likewise of a private commercial nature. I have, with considerable expense and attention, prepared a set of models of crystals, partly solid and partly dissected; and have made arrangements which enable me to supply the public. The dissected crystals are so constructed that they can readily be taken to pieces and built up again in various ways."

"A single glance at the dissected models will enable the student to comprehend why crystals are always rectilinear bodies, bounded by planes, and whence that immense variety of crystalline forms is derived with which the mineral kingdom has astonished the world."

"As the series of solids to be finished on the present occasion will be limited, such individuals who are desirous of receiving sets of them will have the goodness to favour the author with their orders, either in a direct way or through the medium of their booksellers."

"This condition is essential because the author presumes he would otherwise employ his time and labours with more advantage to himself and the public. Further information may be had at the laboratory where several thousand models, both solid and dissected, are ready for inspection." [1638]

These crystal models appear to have been made of pear or box-wood, and are also fully enumerated in the introduction to Accum's *Elements of Crystallography*. In a section titled "Crystallographic Models both Solid and Dissected," 50 models are listed with a variety of collections consisting of subsets of these fifty models available. In another section titled "Models Illustrative of Crystallography Exhibiting the Primitive Forms of Actually Existing Crystals," 87 models are cited. The object of these models "is to familiarize the student with the primitive forms of actually existing crystalline solids, and their metamorphoses of modifications of forms, so as to enable him to see at one view, what they possess in common, and what is peculiar to each crystalline solid." [1639] Accum left England in 1822 selling his business to Frederick Joyce who was a principally a supplier of chemical apparatus. Joyce appears to have gone out of business several years later.

In 1816, in a letter to Thomas Thomson, Nathaniel John Larkin [1781-1855] announced that he had prepared a set of models to accompany a recently published textbook of mineralogy. He described his models fully:

"I have just executed some models to accompany Jameson's Characters; they are in two boxes one of which contains 34 models of the first two plates ... to illustrate Werner's Crystallographic method: the remaining 19 are primitives. They are numbered after the above plates, the first the letter F, and the others P. The price of the whole is one guinea. The may be seen at Mr. Mawe's, Strand; Mr. Bate's, Poultry; and Mr. Jones' Holborn.

I purpose making a complete set to accompany Jameson's Mineralogy, in the same stile, consisting of 249 figures, for 4l. 4s., with the names neatly stamped on each model." [1640]

Around the same time in Germany Karl Eduard Philipp Wackernagel published in 1822 the first and only section of his *Netzen der Krystallmodellen*. This was another series of crystal model diagrams intended to be cut apart, folded and glued together by the reader. In Göttingen, F. Upel prepared and sold in a wooden box a set of 108 wooden crystal models.

[1638] This quotation is copied from, Browne (1925) who does not give the volume or issue number for the original citation.

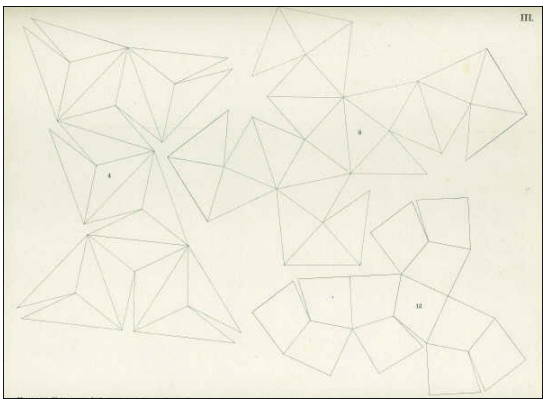
[1639] F. Accum, *Elements of Crystallography*, p. liii-liv.

[1640] N.I. Larkin., "XI. Models of Crystals," *Annals of Philosophy* (Thomson), **??** (1816), p. 315. [The letter is dated 13 August 1816.]

They illustrated the crystal forms depicted in Gustav Rose's *Elemente der Krystallographie*, which had a second edition in 1838. A label glued to the inside of the wooden container provides manufacturer information as well as descriptions of the various models.[1641]

By the 1840's another supplier of crystal models appeared in Great Britain. John Joseph Griffin a member of a family of publishers wrote a *Treatise on Crystallography* for which a series of porcelain crystal models was also available for purchase. The fourth section in the book is a "A Descriptive Catalogue of the Models of Crystals employed to Illustrate this System of Crystallography." (p. 123-137). The models consisted of 120 numbers and with only a few exceptions they all represent crystals that could be observed in minerals. Their size was from 2 to 4 inches in diameter and were of a 'Cream Coloured Biscuit Porcelain.' Each of these models was stamped with the letters P, M, T to indicate Griffin's crystallographic notation, which may be used today to identify these models. The entire suite could be purchased in a packing case or a separate hardwood cabinet with four divided trays and 120 paper boxes.[1642]

In 1849 Hermann Franz Moritz Kopp included at the end of his *Kristallographie* seven lithographic plates intended to be cut apart, folded and glued to provide a series paper crystal models to the interested reader. This feature was repeated in the second edition of 1862, and ultimately published separately with the appearance of a fifth edition in 1885.[1643] This was a cheap, simple method of providing a student the ability to have crystal models at his use to study interfacial crystal symmetry. Consequently, Gustav Adolf Kenngott prepared his *Sechzig Krystallformennetze zum Anfertigen von Krystallmodellen* that first appeared about 1852 and extended through at least 22 editions published in Vienna and Prague to 1873. In this work, Kenngott shows 60 cut apart crystal models that were used by students. The models were also redesigned and printed on 28 thick paper plates starting in 1890 in Esslingen near Stuttgart, and published by the same firm that printed the famous Kurr-Kenngott colored mineralogy. This is a type of publication that would be reworked in J.B. Jordan's *Crystallography: A Series of Nets for the Construction of Models Illustrative of Simple Crystalline Forms* (London, Thomas Murby, 1921).



Paper Models (Kenngott, 1890)

Although paper models were useful for students, more durable materials were required for the instructors in colleges and universities where crystallography and crystal symmetry were taught. In 1876 in the first edition of Paul Groth's *Physikalische Krystallographie* the German mineralogist Carl Hintze offered collections of loose natural crystals, minerals specimens, as well as four collections of wooden crystal models. They were available in sets of 30, 80, 100, or 675 pieces with prices ranging from 18 to 420 Marks.[1644] At this time it seems that Hintze was one of the largest suppliers of crystal model sets.

The collection offered by Hintze may have been supplied by the German dealer Krantz who published in 1862 a catalog of 675 wooden crystal models.[1645] In 1895 by the time of the third edition of the *Physikalische*

[1641] *Personal communication from K. Blahd, 1991.*

[1642] J.J. Griffin, *Treatise on Crystallography*, 1841, advertisement at end of book.

[1643] H. Kopp, *Sechs Tafeln mit Netzen zu Krystallmodellen zu der Einleitung in dei Krystallographie.* 5th Auflage. Braunschweig, 1885.

[1644] P. Groth, *Physikalische Krystallographie*, 1876, p. 527.

[1645] A. Krantz, firm, *Catalog einer Sammlung von 675 Modellen in Ahornholz zur Erläuterung der Krystallformen der Mineralien.* Bonn, 1862. [citation taken from *Katalog der Bibliothek der Königlich Sächsischen Bergakademie Freiberg*, 1879, p. 369.]

*Krystallographie*, Groth was able to include an advertisement from by far the best known supplier of crystal models until the present day. It is the mineral dealership established in 1833 by Adam August Krantz,[1646] which is certainly one of the oldest continuous mineral dealerships in existence, if not the oldest. In their 1895 listing they offer eight crystal model sets prepared in pear wood and 5 cm (approx. 2 inches) in size, although some models were available in a 10 cm size (approx. 4 inches). The sets consist of:

*a.* Collection of 30 crystal models showing the chief forms.

*b.* Collection of 50 crystal models.

*c.* Collection of 80 crystal models including all the pieces found in *a* and *b* together with models useful in teaching high schoolers the important crystal combinations as well as twinning.

*d.* Collection of 132 crystal models showing the chief forms also all hemiedrischen and tetartoëdrischen and the commonly encountered combinations in nature brought together by Carl Hintze.

*e.* Collection of 56 models of distorted and pseudosymmetric crystal forms arranged by Julius Hirschwald. This collection contains single crystal models that show equivalent faces in disproportionate distance from the center or present a pseudosymmetric character in the relations of the combination making the actual crystal class that the model represents known by goniometric measurement.

*f.* Petrographic-crystallographic collection of 100 models arranged according to H. Rosenbusch's *Mikroskopische Physiographie der petrographisch wichtigen Mineralien*, 3rd edition, Stuttgart, 1893.

*g.* Mineralogical-crystallographic collection of which two separate sets were made. (1) Collection of 743 models containing all the typical crystallized minerals and brought together by Paul Groth for Krantz in 1880.[1647] (2) Collection of 213 models that since the appearance of the 1880 set have been recognized and brought together by Paul Groth in 1887 and thus supplementing with little or no duplication the original 743 models for a total of 956 models!

*h.* Systematic-crystallographic collection also available in two separate sets. (1) Collection of 396 models commonly found in the important textbooks and showing standard crystal forms and combinations together with a catalog prepared by Paul Groth. (2) Collection of colored models showing the hemiëdrischen and tetartoëdrischen forms, prepared by Groth and based upon his *Lehrbuch der physikalischen Krystallographie*, 2nd edition, Leipzig, 1885.

Krantz went to extraordinary measures to supply a wide range of crystal model sets. In addition to the aforementioned wooden models, they supplied eight collections crystal models made from plate glass that ranged from 10 to 54 pieces. In addition, Krantz had available a variety of larger models made from a sturdy cardboard that ranged from 8 to 12 inches in diameter. The cardboard collection proposed by the Prague mineralogist Karl Vrba [1845-1922] contained 280 crystal forms that besides the common forms includes many combinations and twins.

The Rochester, New York firm of Ward's

[1646] Adam August Krantz (born: Neumartk, Schliessen, Germany, 6 December 1808; died: Berlin, Germany, 30 March 1872) studied 'Geognosie' at the Freiberg Bergakademie earning a Ph.D. In 1833, he founded in Freiberg the 'Mineralien-Geschäft von Krantz' (Krantz' Mineral Shop). In 1837, he moved the firm to Berlin, and in 1850, he reestablished the company in Bonn, changing its name to 'Rheinisches Mineralien Comptoir.' In 1841, Krantz made the first geological map of Elba, Italy, and in 1866, he purchased the mineral business of the Paris dealer, Saemann. By July 1847 Krantz was able to claim in an advertising brochure that he had 750 different mineral species in stock with between 2500 and 3000 varieties and localities represented. In addition, various rock types and fossils could also be supplied. Krantz' personal mineral collection of about 14,000 specimens was acquired by the University of Bonn in 1872.

The Krantz mineral dealing firm survives to the current time. After the founder Adam August died in 1872, his son-in-law, Captain Theodor Hoffmann managed the company for 16 years, but he knew nothing of mineralogy. In 1888, the son of the founder, the mineral dealer and crystallographer Friedrich Ludwig Robert Krantz, took over management of the firm. Under his leadership the firm of Krantz became famous worldwide. He died in 1926. His wife Olga and nephew Fritz took over the business. Olga operated the firm through World War II by trading goods for specimens. For example, sewing material for fossil cronoids. The nephew, Fritz Krantz, managed the firm from 1948 until 1974. His interests were primarily palaeontological. His daughter, Renate Krantz, who had a degree in geology, managed the firm from 1974 until her death in 1995. In turn her daughter, Ursula Müller-Krantz manages the firm to the present time.

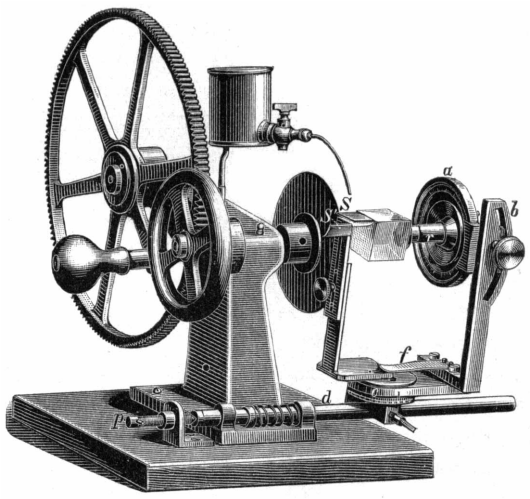
[1647] A catalog listing the various crystal forms prepared by Paul Groth accompanied the set, but I have never been able to trace a copy.—cpschuh.

Natural Science Establishment, Inc. has been the agent for Krantz in the United States. They supply all of the crystal model collections. As early as 1906 Ward's was advertising the availability of crystal models.[1648] Because of the popularity of Edward S. Dana's *Textbook of Mineralogy* (1st ed., New York, 1877) a series of collections based upon its crystal diagrams and numbering are prepared and sold through Ward's. These collections were made in wood in sizes from 2 to 12 inches or in cardboard.

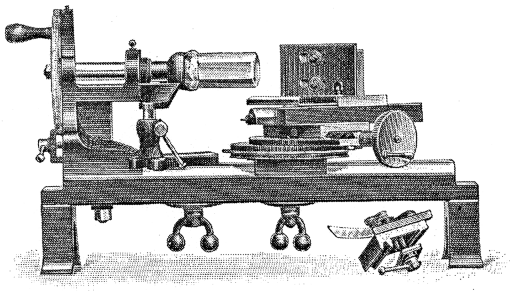
Herbert P. Whitlock in his *Guide to the Mineralogic Collections of the New York State Museum* (1902) includes at the end a series of models that could be cut out, folded, and taped to form basic crystal forms.

### 14.9.1 Crystal Model Making Apparatus

In the late ninteenth century it became useful to cut plates of various shapes and dimensions from the transparent crystals of a wide range of minerals. These plates were used in various mineralogical experiments, especially in measuring indexes of refraction. To facilitate the creation of the plates, the German insturment makers manufactured and sold the cutting equipment. Apparently, early on these insturments were used to make crystal models from plaster, wood, glass and other materials.

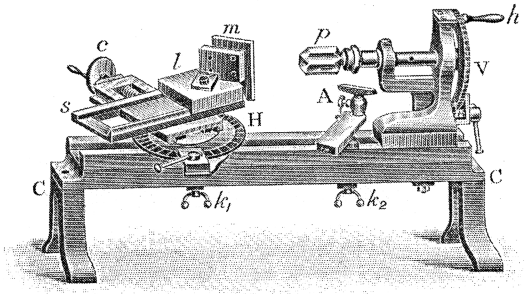



Fuess' Apparatus, 1889



Goldschmidt's Apparatus, 1920

The famous insturment maker R. Fuess created a hand cranked machine to cut crystal shapes.[1649] It was originally sold to cut crystal plates by forcing a cutting grit in a slurry to the blade that would cut the mineral, but was readily adapted to cut models of crystals.




Goldschmidt's Apparatus, 1908

Rarely thereafter, articles appeared in the professional literature describing equipment that could cut crystal models. In 1899, the renowned German crystallographer Viktor Goldschmidt published perhaps the earliest article describing an apparatus specifically designed to make crystal models of plaster.[1650] This article explains the theory behind creating a signally terminated crystal model in plaster. He continued to refine his apparatus and published another article in 1908.[1651] This article also contains a diagram of the apparatus to clarify the process.

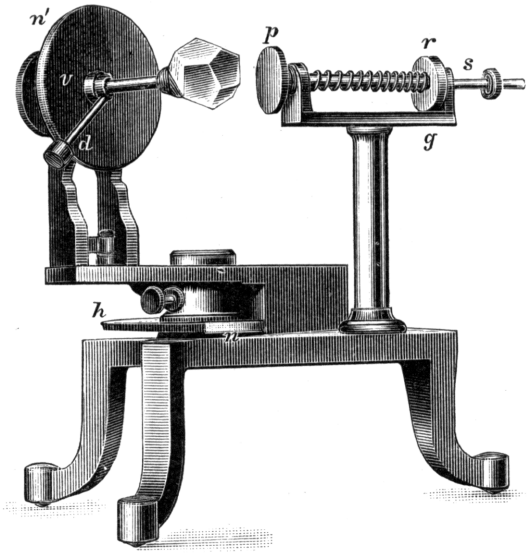
[1648] Advertisement, *The Mineral Collector*, **13** (1906), no. 2.

[1649] R. Fuess., "Über eine Orientirungsvorrichtung zum Schneiden und Schleifen von Mineralien nach bestimmten Richtungen," *Neues Jahrbuch der Mineralogie*, **1889**, part 2, p. 181-185.

[1650] Viktor Goldschmidt., "Über einen krystallmodelierapparat," *Zeitschrift für Krystallographie*, **31** (1899), 223-8.

[1651] Viktor Goldschmidt., "Krystall-Modellierapparat 1908," *Zeitschrift für Krystallographie*, **45** (1908), 573-6.

In 1914 Friedrich Stöber refined Goldschmidt's original design improving the accuracy of the apparatus to 1/2 degree arc in making the interfacial angles on the plaster model. He was able to achieve this by making his modifications to a two circle goniometer. Stöber includes two figures to clarify the process including a good one of the actual machine.[1652]




Stöber's Apparatus, 1914

In 1915 Fredrich Eugene Wright described a two-circle crystal-grinding goniometer for grinding faces of any desired orientation on a crystal and accurate in position to one-half minute of arc.[1653]

In America John M. Blake authored an overview of methods for drawing crystals and making crystal models.[1654] Blake describes his own unique device for shaving blocks of plaster to the correct form of a crystal. He includes a picture of the actual homemade device.

In 1927 Charles Palache and one of his students Lyman W. Lewis adapted Goldschmidt's original apparatus that was used to create plaster models into a unit that could create wooden crystal models. Their article explains Palache's modifications to the original idea so that both single and double terminated crystals could be sawn from a wood block. The illustrations show crystal cutting apparatus as well as the "Centering Vise for cutting doubly terminated wooden models.[1655]

## 15.0 Illustrated Works[1656]

Since well before the invention of writing, pictures were used ot convey information and ideas between humans. The earliest surviving manuscripts commonly contain illustrations to support the companion textual descriptions. This is not suprising since some of the earliest evidence of man's intellectual curiosity manifests itself in the magnificent cave paintings that show realistic depictions of game animals, and date to 20,000 years ago. Pictures were the first method invented by humans to permanently pass ideas to each other, and to future generations. Althought good quality pictures alone can give useful information, it is the combination with a descriptive text, where the sum is far greater than the parts would predict.

Illustrations can be realistic, idealized, or imaginary, depending on the topic under consideration. An illustration can visualize things that would otherwise be impossible to see. For example, a cross-section of the earth showing the crust, mantle, and core. Or, it may realistically illustrate an intricit scientific instrument, whose function is unclear without an accompanying text that describes the functionality. The link between the text and illustration is a strong bond.

[1652] Friedrich Stöber., "Über einige neue krysstallographische Apparate," *Zeitschrift für Krystallographie*, **54** (1914), 273-88.

[1653] Fredrich E. Wright., "A new crystal-grinding goniometer", *Journal of the Washington Academy of Sciences*, **5** (1915), 35-41, 3 figs

[1654] John M. Blake., "Crystal drawing and modeling," *American Journal of Science*, **43** (1917), 397-401.

[1655] Charles Palache and Lyman W. Lewis., "A saw attachment adopting Goldschmidt's model cutting machine to the sawing of wooden models," *American Mineralogist*, **12** (1927), 154-6, plates IX & X.

[1656] Further historical information may be found in: Wolfhart Langer., "Die Paläontologische Buchillustration" (**2**, p. 361-409) in: Claus Nissen, ed., *Die Zoologische Buchillustration.* Stuttgart, Hiersemann, 1978. 2 vols. [History of illustrated palaeontogical works.] • Martin J.S. Rudwick., "The emergence of a visual language for geological science 1760-1840," *History of Science*, **14** (1976), p. 149-195.

### The Scientific Problem

No matter how eloquent and accurate the description, illustrations can never be replaced for imparting information to the reader. Conversely, an illustration of a mineral, can never convey the sense of density, feel, smell, etc. that are easily listed in a short descriptive table. SO the main purpose of a mineral illustration in the technical literature is usually to collect information from the description, and if possible to enhance the description.

This simple idea is, however, very difficult to accomplish in mineralogy. In all the illustrations that have been created in natural history, minerals have always taken a subordinate position to plants and animals. Perhaps because the biological subjects are very familiar to humans, illustrations comprising only a few lines, if drawn skillfully, can render to the viewer a sence of these subjects. For example, a stick figure made of a circle for head, and lines for body, legs, and arms is easily seen as a human form. Minerals on the other hand are extraordinarily difficult to illustrate well. There are many causes for this, especially in the earliest attempts, where the picture of a mineral resembles nothing more than an errant blob of printer's ink. The first objective of a mineral illustration, then, is to enhance the description given in the text, by accurately and scientifically picturing the mineral.[1657]

Even with today's best photographic techniques, effectively illustrating a mineralogical text is a difficult task. Imagine then in the first centuries of printing, where a skilled woodcut artist was necessary to create the illustration from the author's design, and the process becomes even more complex and correspondingly difficult.

### The Artistic Problem

More than simply illustrating a mineral, an intangible quality exists in some mineral illustrations, that make them works of art as well. The illustrator has added something to the design of the picture to make it not only a good depicition of the mineral in question, but to make it appealing to the viewer. Such artistic enhancements have occurred from the first printed mineralogies. What that quality is, can not be judged, but some mineral illustrations leap out as superior examples.

## 15.1 Rendering Minerals

Thousands of illustrations relevant to mineralogy or crystallography have appeared in books, periodicals, and empera over the centuries. Some individual works can boast of containing over 1,000 illustrations within the text. These pictures vary widely in quality and subject, but illustrations of minerals have existed since almost the earliest treatises to treat mineralogy were printed. The old herbals were the first to use illustrations to help convey ideas in the text, albeit they were allegorical in nature, and to the modern reader have nothing particular to do with the mineral discussed in the text. However, as time progressed, better images were introduced, usually through the improvement of technology to duplicate the image in the books.

### Illustration Techniques

The earliest book illustrations are descriptively called "woodcuts" because this printing method uses a relief carved from wood to transfer the design to the book. Beginning with a block of wood about 7/8 inches thick, a design is first drawn on a surface of the block in a mirror image of what is wanted in the book. The wood is then carved so that those areas which are to appear white are cut away, leaving the rest of the surface as ridges and plateaus. By applying ink to the surface and pressing to paper the design is transferred. This is the earliest of the mass production techniques to print a picture and is usually found in books published in the fifteenth, sixteenth and seventeenth centuries. The method was not adequate for fine detailed drawings, however, and as more realism was demanded of the illustrations, new techniques were tried.

It had been noted quite early that using engraved copper plates in place of wood produced illustrations with clear, sharp lines. Consequently, detailing not easily obtained from woodcuts became the trademark of copper plate illustrations, which came into prominence

[1657] In other fields, illustrations are sometimes required to define new species. It was proposed as early as 1887, that if the description of a newly discovered fossil was not accompanied by an accurate illstration, the species was invalid.

in the eighteenth and nineteenth centuries. In fact, full page illustrations in books are still referred to "plates", a lasting reference to the success of copper plate engravings. The process involves first sketching the design on a sheet of paper, the back of which is then rubbed with chalk. A highly polished copper plate which has been coated with beeswax and then smoked black over a candle is now utilized. The paper is laid chalk side down on the plate and the lines of the design traced with a sharp point, which transfers them to the wax. Using these chalk marks as a map the design can now be scratched into the copper surface below the wax with a sharp pointed tool. After the design has been scratched out, the plate is engraved by means of a graver, which acts like a miniature plow throwing copper in front of it. In order to get a clear line, the ridges created by the graver as it cuts into the copper are removed with a scraper, and the plate is again polished. Ink is applied and wiped from the surface so that only the engraved lines retain any. Pressing dampened paper on the plate will now transfer the engraved design. The work involved in making plates was both time consuming and expensive, requiring expert engraves and artists. It is no surprise then that other cheaper, more efficient methods were sought.

Lithography seems an ideal solution to the complexities of engraved plates. The process involves blocks of a fine grained Bavarian limestone on which a flat drawing surface is ground. Upon this surface the artist draws his design with a special lithographic crayon of a greasy composition. An 'etch' consisting of acid, water and gum arabic is applied to the total surface with a brush. This effectively fills the pores of the limestone not previously coated by the crayon. Next, the surface is cleaned with a solution of gum arabic and water and then polished such that the gum is removed from the crayon of the design while leaving it on the undrawn surface where it is allowed to dry. Turpentine is now used to remove the crayon. At this stage, even though nothing of the original crayon design is visible, the grease lines of the drawing are still embedded in the stone. If ink is now applied to the stone, the greased areas will absorb while other areas repel. Thus only the lines of the original drawing will be inked, and a dampened paper pressed to the surface will transfer the design. Lithography has the advantage over engraving of needing only an artist with the proper techniques and over woodcuts of being able to produce detailed prints. Yet by themselves these methods could not accurately convey the beauty of minerals.

All of the printing techniques described so far were based on schemes involving black ink on white paper; however, it was known early that color added another dimension to pictures. It is not surprising then that dull black and white illustrations started to be hand colored. This was not a cheap exercise, however. Hand coloring was labor intensive, involving skilled colorists, and in the beginning only very wealthy collectors could afford to have books so treated. Yet as time progressed demand became greater, and subsequently more and more volumes with colored plates began to appear. Likewise, the skill of the artists increased so that the plates could be made very realistic in appearance.

## 15.2 Black and White Illustrations

**REWORK:** Minerals have many properties that combine to make them recognizable in physical specimens. One of the chief properties is that they are distinctly colored, and attempting to render illustrations of them without color is a particularly difficult challenge. This is clear in the many black and white pictures starting in the incunubula period and extending down thorough the centuries that show only black and whit blobs on the page—sort of a mineralogical Rochscher ink test! Relatively few works contain really excellent black and white pictures of minerals.

The earliest illustrations of minerals occurred in the late fifteenth century just a few decades after the invention of mechanical printing. They are found for the most part in the Herbals of the time, which were a popular volume containing folk medicine recipes and other information that was thought to be useful. Most of the volume in dedicated to the medical uses of plants and many of the pictures show botanical subjects. But the



Borax found on a Toad (1483)



Bloodstone cures Nosebleed (1483)

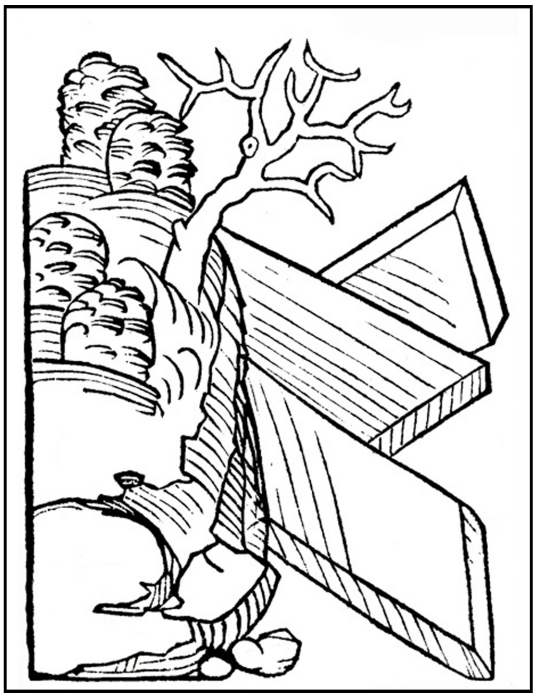
last part deals with minerals and gems and their supposed medical virtues. This section is likewise illustrated with woodcuts, which are allegorical in nature usually showing either the source for the mineral or its use. Thus, one early woodcut shows the harvesting of borax from the head of a toad, while the dipiction of bloodstone shows it in the treatment of a nosebleed. At the time, such believes were commonly held among the population, and the pictures reinforced the accompanying the text description.

The honor for the first illustration of a crystallized mineral in a printed book appears to belong to the *Hortus Sanitatis* published on June 23, 1491 by the Mainz printer Jacob Meydenbach. This work is a member of a popular type of middle age literature known as a Herbal. As a group, this type of book records the late medieval view of the natural world in terms of how nature could be used to benefit man. Relationships and the uses of plants, animals and minerals discussed in these texts offers insight into the early development of medicine, agriculture and pharmaceutical therapies for the common person. The Meydenbach describes various plants, animals and minerals used in pharmacy in 1066 chapters. Included among the illustrations of the 144 chapters devoted to mineralogical substances there is an apparently idealized picture of a gypsum specimen with three crystals, drawn out of scale, but without any doubt of its species, right down to the striations often found upon the crystal faces. The description of the "lapis specularis" (mirror stone) as the text refers to the species is derived from Pliny.[1658]

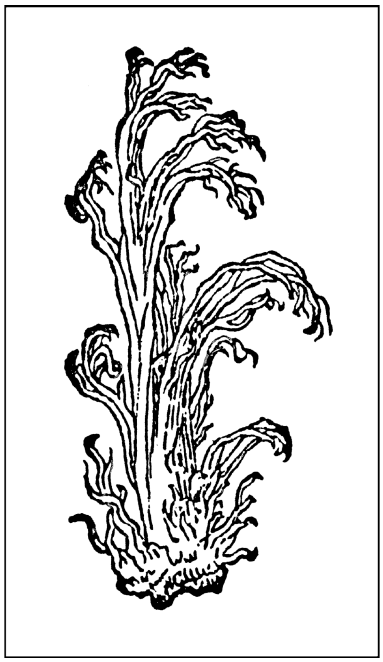
Other pharmaceutical and medical works of the early sixteenth century included some illustrations of minerals and fossils. These include the other editions of the *Hortus Sanitatis*, Loncierius' *Naturalis Historiæ* (1551), and its numerous German translations published under the title *Kräuterbuch* from 1557 onwards, and Entzelt's *De Re Metallica* (1551). It was however the more famous work of Gesner that is often credited with presenting the first mineralogical illustrations of the sixteenth century.

Conrad Gesner was born in Zurich, the son of a furrier with many children and little

[1658] S.E. Pober., "The first book illustration of a mineral crystal," *Matrix*, **1** (1988), no. 3, p. 44.



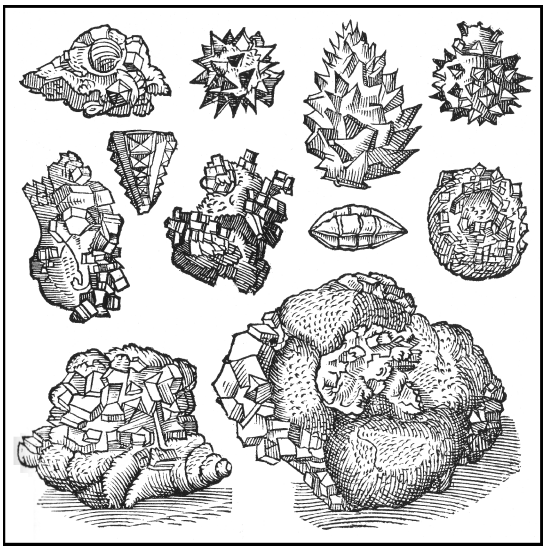
Gypsum (Hortus Sanitatis, 1491)



Silver (Gesner, 1565)

money. Although his father was killed in battle fighting for the Protestant cause when Gesner was only 15, he nevertheless received a good classical education, and at first planned to enter the ministry. But his strong interest in natural science diverted him onto another path. In 1533 he was awarded a traveling scholarship, and spent two happy years in self-directed study in Bourges and Paris. He then traveled first to Strasbourg and then to Basle, Switzerland where he earned his doctorate in 1541. He finally settled in Zurich where he continued to pursue his interests in botany, zoology and medicine.

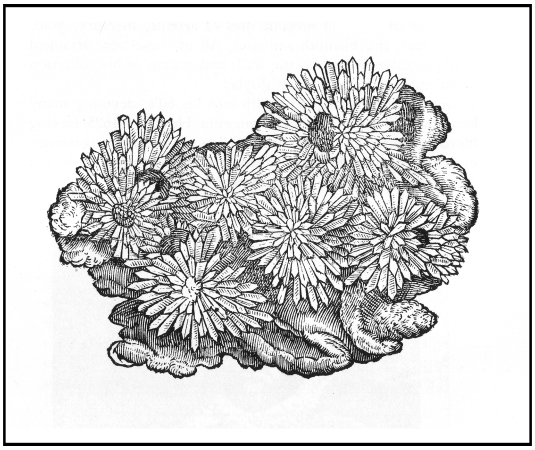
Gesner illustrates some silver mineral specimens in his famous *De Omni Rervm Fossilivm Genere, Gemmis, Lapidibvs, Metallis* (1565). He published over 70 books in his lifetime, plus 18 more that were still in manuscript form at the time of his death. He had been influenced by Agricola's work on mining and ore mineralogy, and in the early 1560's decided to expand his activities to include mineralogy. He assembled a mineral collection which he used as the basis for illustrations commissioned from hired artists (whose names have long since been lost to history). It was Gesner's intention to later publish a more thorough volume on minerals, which would surely have been large and magnificently illustrated, but he contracted the plague that same year and died at the age of 49. His mineral collection survives today, at least in part, and is incorporated into the collection of the Natural History Museum of Basle.



Bauhin, 1598

Jean Bauhin [1541-1613] was born to French Protestant parents living in exile in Basle, Switzerland. He was educated in Basle and in Zurich under the famous naturalist Conrad Gesner, and settled in Lyon, France in 1563 to begin his medical practice. Renewed religious persecution forced him to return temporarily to Switzerland in 1568, but in 1571 he was appointed physician to Duke Frederick of Württemberg, a gracious and supportive patron. Despite his official occupation as physician, however, Bauhin's real love was botany, and he collaborated with Conrad Gesner before Gesner's death in 1565, on a great botanical compendium. Bauhin and Gesner spent many pleasant days together collecting plant and mineral specimens in the Alps.

In 1598 Bauhin published his eclectic study, *Historia Novi et Admirabilis Fontis*, inspired to some extent by Gesner's work. *Historia Novi* deals primarily with the natural springs at Boll, in the duchy of Württemberg, including a chapter on the local natural history which was, it turns out, rich in crystallized minerals (the chapter is entitled Regarding the metallic minerals which miraculous nature has skillfully shaped in the bowels of the earth). A total of 211 woodcut engravings depict mineral and fossil specimens in Bauhin's collection. These are the only mineralogical illustrations to appear in the 16th century, other than those of Gesner in 1565.



Quartz (Imperato, 1599)

Imperato illustrates some quartz mineral specimens in his famous *Dell'Historia Natvrale* (1599). These pictures are readily recognizable and were copied across a wide number of natural history works of the succeeding two centuries. A highly interesting and splendidly illustrated publication dealing with natural history, including botany, mineralogy, metallurgy, mining, zoology, etc. The dedication is to Juan Fernßndez de Velasco, duque de Frías. In his address to the reader, Imperato names Niccolò Antonio Stigliola as having consulted on the text. There are 126 woodcuts in the text. These are of gems, plants, sea creatures, reptiles, and insects. Mortimer suggests Mario Cartaro as artist of these blocks. First edition printed in a small edition for friends of Imperato. The striking double–page frontispiece shows his magnificent library and museum, a vast collection of prepared animals (i.e., birds, fish, insects, and a huge crocodile fastened to the ceiling) and several shelves of books. The text woodcuts show plants, animals, minerals, etc.

Basilius Besler illustrated a wide variety of mineral specimens in his famous *Fasciculvs Rariorvm* (1622), which was contined by his nephew Michael Rupert Besler in the *Gazophylacium Rerum Naturalium e Regno Vegetabili, Animali & Minerali* (1642). The works show a treasury of natural objects from the realms of the vegetable, animal and mineral that were contained in their natural history cabinet. It contains standard items including a unicorn horn, a beak of a hornbill, a bird of paradise, a carved nautilus shell, an 'Arcimboldo' grotesques of shells, pyritzed ammonites, asbestos, 'ruin' marble, engraved gems and antique coins. Rare plants and birds are illustrated along with ethnological items such as a Brazilian Indian girdle made from nuts of the Brazilian tree *Cerbera ahovai*. There are also many mineral specimens which except for the quartz crystals are unrecognizable. Images from this work were later copied by Michael Valentini in his *Museum Museroum* (1714).

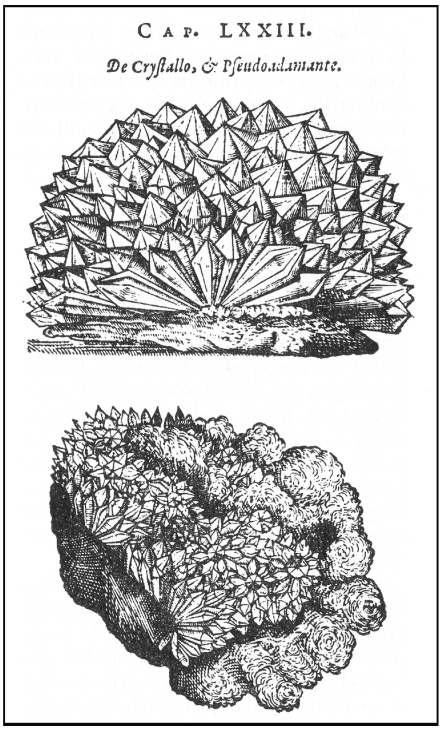
Anselmus Boëtius de Boodt illustrates several quartz mineral specimens in his famous *Gemmarvm et Lapidvm Historia* (1636). This is one of the most important




Besler, 1642

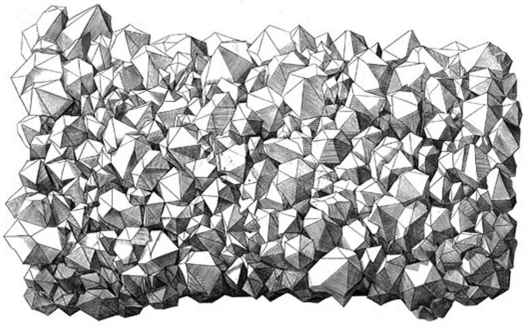
mineralogical works of the seventeenth century, marking a transition over previous lapidaries. It is of particular interest as a manual describing minerals that is more detailed, more extensive, more critical and more systematic than many earlier works. It was a well known and influential book, going through several editions and frequently being cited by other authors. A new era was marked with its publication. One in which the believes of the past began to be challenged, and the researchers began to use hypothesis and experimentation to present new ideas. Above all, Boodt's work is an early example of a treatise on mineral substances that departs from a simple alphabetical arrangement in persenting its description of stones.

Georg Eberhard Rumpf illustrates some mineral specimens, including quartz, in his famous *D'Amboinsche Rariteitkammer* (1705). The 60 magnificent copper engravings may be separated into the following categories:



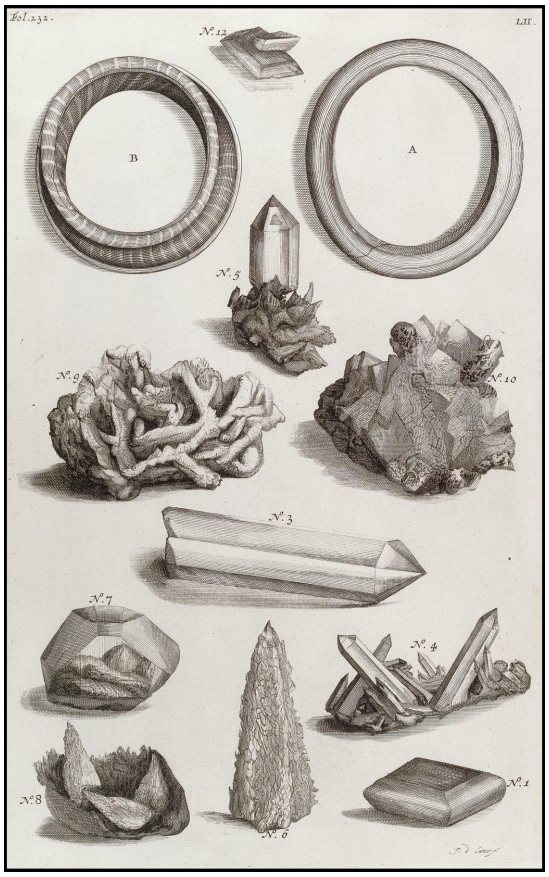

Quartz (Boodt, 1647)

crabs (12), sea-urchins & starfish (4), snails & muscles (33), and petrifications and minerals (11). There is also an engraved title page, a beautiful engraved frontispiece portrait showing Rumpf and 4 engraved vingettes.



Quartz (Mercati, 1717)

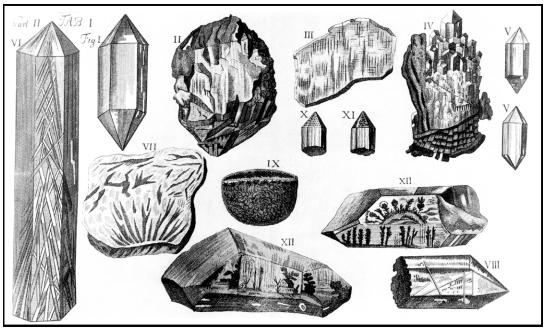
Michele Mercati [1541-1593] was born to a wealthy family in San Miniato, between Pisa and Florence, Italy. His father was a prominent physician , and his grandfather was a noted humanist and philosopher who moved in the highest scholarly circles. Mercati studied first in San Miniato, then enrolled in the University of Pisa for his degree in Philosophy




Rumphius, 1705

and Medicine. There he studied under Andrea Cesalpino (1519-1603), a celebrated physician and botanist, and later to be the author of De Metallicus ("On Minerals") (1596). The two became good friends for life. Mercati earned his degree in 1561 and opened a medical practice in Rome, where he so distinguished himself during an epidemic there that Pope Pius V called him to the Vatican and offered him the post of Prefect of the Vatican Botanical Gardens. In 1577 Mercati was officially received among the "familiars" of Pope Gregory XIII who, having learned of Mercati's passion for mineralogy, suggested that he create a natural history museum inside the Vatican, focusing on minerals. Mercati was delighted by this idea and worked for many years building the collection while serving as Chief Physician under a succession of Popes. He had 19 large, expensive, custom-made cabinets constructed to house the collection in a room in the Pio-Clementine Museum. The collection eventually ranked among the largest and best in all of Europe.

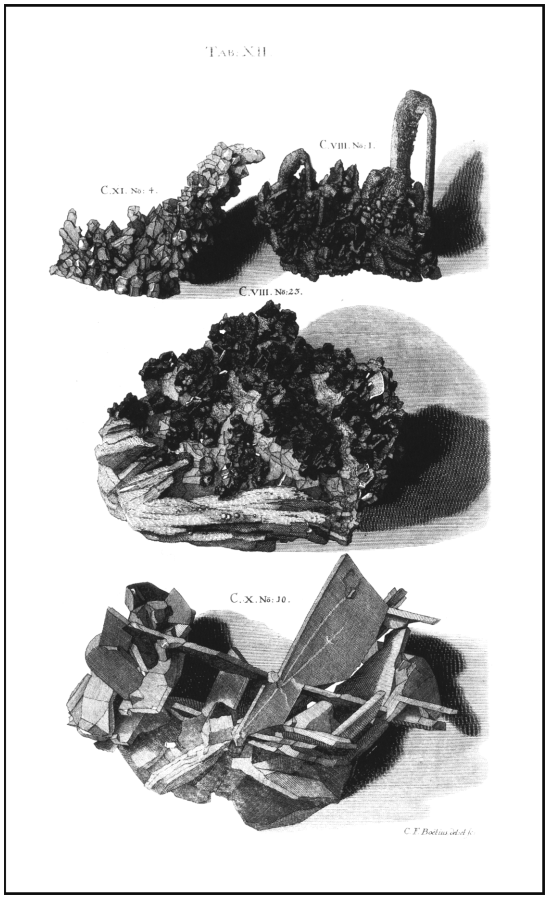
Mercati spent years writing a scholarly description of the collection in his spare time, and having 127 high-quality copper-plate engravings of specimens prepared, but by the time of his death he had managed to cover only the first nine cabinets containing the non-metallic minerals. His manuscript and engravings were claimed by his relatives and placed in storage, and his magnificent collection eventually was reduced to nothing by pilferage. The manuscript and its illustrations were rediscovered and published as Metallotheca Vaticana in 1717, but by that time the science of mineralogy had passed him by and his pioneering work from the 16th century, which would have been so significant in its time, was generally ignored. The illustrations shown here are from a copy in the Mineralogical Record Library.




Brückmann, 1727

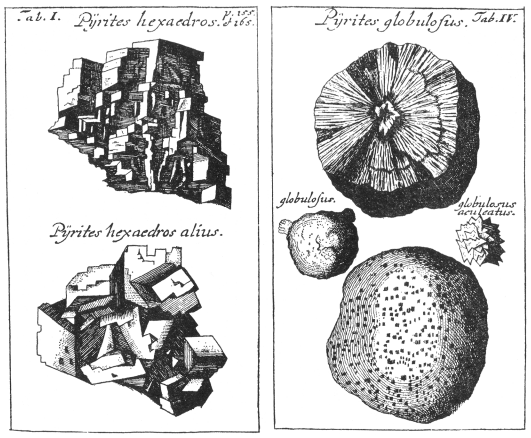
Franz Ernst Brückmann illustrates a variety of mineral specimens in his famous *Magnalia Dei in locis subterraneis* (1727-1734). This work is an early geographically divided guide to mining throughout Europe with references to mining in the New World. Part one uses individual chapters to treat the countries of Portugal, Spain, France, Germany, England, Scotland, Ireland, The Netherlands, Switzerland, Italy, Denmark, Norway, Sweden, Poland, Russia, Hungary, Turkey and Greece. There is also considerable additional discussion of mining activities in America and Spanish America. The text recounts various descriptions of individual

mines and entire districts and the materials mined. These descriptions include frequent mention of the individual minerals processed, which in some cases are illustrated on the accompanying plates. Details are also included about the discovery and history of the mining operations. The second part retains the same format as the first, but greatly expands information by including much new material.




Hebenstreit, 1743

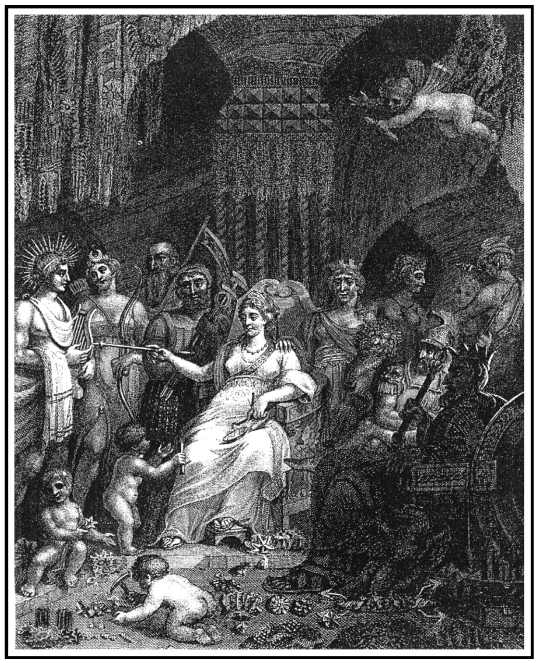
Mineral specimens from the collection of Johann Christoph Richter [1689-1751] are well illustrated in the famous *Mvsevm Richterianvm Continens Fossilia, Animalia Vegetabilia* (1743). Richter was a wealthy banker and member of the legislature in Leipzig, and in his leisure collected all types of natural history specimens, but specialized in minerals and crystals. He engaged Johann Ernst Hebenstreit [1702-1757] a renowned scholar, mineralogist and naturalist to curate his collections. Hebenstreit was born to a poor family in Neustadt, Germany, but his intelligence and perseverance allowed him to obtain a medical degree in 1723 and in 1730 he became a professor of medicine at the University of Leipzig. In 1743, Hebenstreit's description of Richter's collection appeared as a folio volume, with a thorough and well-organized text illustrated by engravings of 114 mineral specimens from Richter's collection on seventeen excellent plates. These plates, designed by the Leipzig-born engraver and watercolorist Christian Friedrich Boetius [1706-1782], show the finest crystallized specimens contained in the collection. They are also some of the best engraved images of mineral specimens prepared in the eighteenth century.




Pyrite (Henckel, 1725)

Johann Friedrich Henckel illustrates some pyrite mineral specimens in his famous *Pyritologia: oder: Kieß-Historie* (1725). Henckel, director of the mining works at Freiberg, was called by Partington the "father of mineral chemistry." In the famous *Kieshistorie* he has written a monograph on the single topic of pyrite. Henckel recognizeds three types: golden iron pyrites, golden copper pyrites and white arsenic pyrites. Within the body of the text, he proceeds to describe, experiment and speculate upon each of these types. Henckel uses physical properties such as hardness and crystal form, chemical composition including the amounts of sulphur,

arsenic, copper, etc contained, and speculates on why pyrite is usually found in association with rich veins of ore. It is an encyclopedic work on the subject, and exerted a strong influence of subsequent investigators engaged in mineral analysis. The attractive and charmingly primitive frontispiece depicts ore being transported from the mine to a smelting shed and other aspects of mining life. The plates depict pyrites in their various forms.

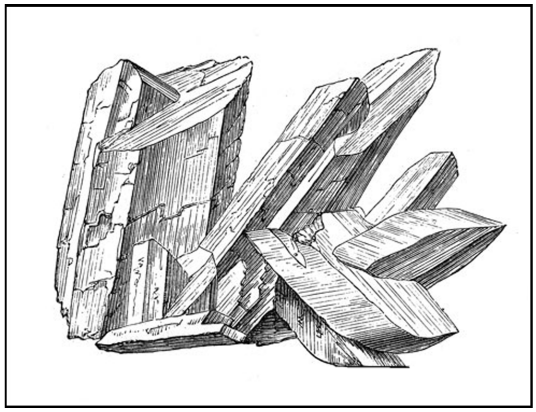


Goddess of Mineralogy (1817)

Contained in the *Encyclopaedia Londinensis* published in 1817, there is a remarkable image, described thusly:

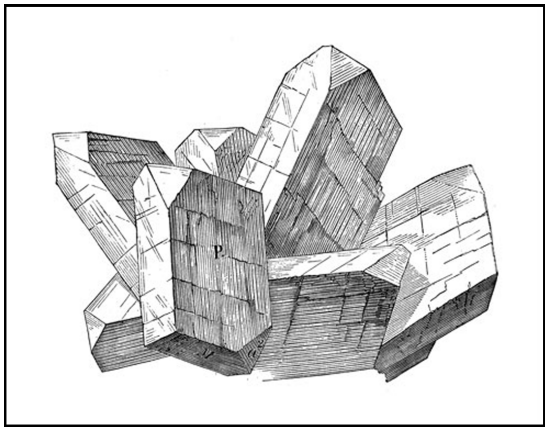
The Goddess of Mineralogy sits in a vast grotto, enriched with the brightest productions of subterraneous nature, the Goddess of Mineralogy holds her high court, seated on a throne of solid gold, the arms of which are supported by Gryphons, the fabled guardians of hidden treasures, and attended by Cybele and Vulcan, representing Earth and Fire, the two principal agents in the formation of minerals. She is surrounded by several groups composed of the gods and goddesses who preside over metals and precious stones: Apollo, in allusion to gold and the topaz; Diana, to silver and the selenites; Saturn, to lead and the diamond; Jupiter, to tin and the sapphire; Mars, to iron and the ruby; Mercury, to quicksilver and the amethyst; and Venus, to copper and the emerald. Several gnomes are busy in search of specimens of precious ores, and present them to the goddess, who, with the scales in one hand and a sceptre of Touchstone in the other, determines to what class of minerals they belong.

Joseph Friedrich Wagner *Notizen Über die Mineralien-Sammlung ... Von Crichton* (1818) describes and realistically illustrates Sir Alexander Crichton's fine collection of Russian minerals. Crichton's collection was eventually sold at auction in April 1827 [for a description of this catalog, see under Crichton]. The volume begins with an historical introduction discussing the collecting of minerals in Russia, including brief sketches of the prominent collectors and their collections. Descriptions of Crichton's finest specimens follow, including numerous topaz, beryl, and tourmaline crystals. Complimenting many of the descriptions are the plates which contain the author's very good renderings of many of the discussed specimens. Wagner also executed the fine portrait of Gotthelf Fischer von Waldheim that is used as a frontispiece.

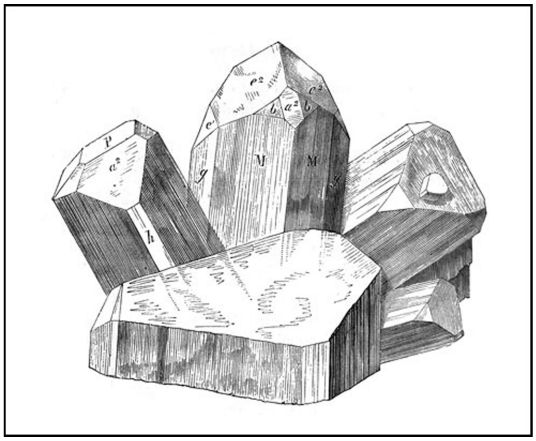


Gypsum (Burat, 1864, Fig. 114)

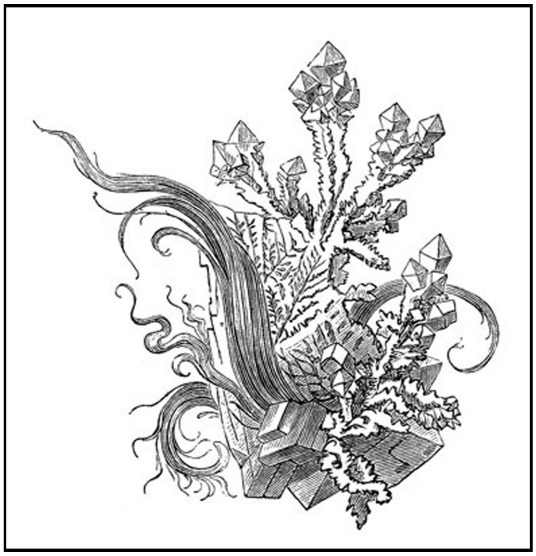
Amédée Burat [1809-1883] earned his degree in geology at the School of Mines in Paris, where he was able to study their superb and historic mineral collection. He became a professor of Mineralogy, Geology and Mining at the École Normandie in 1838, and later joined the faculty of the École Centrale des Arts et Manufactures in Paris. After a teaching



Barite (Burat, 1864, Fig. 119)

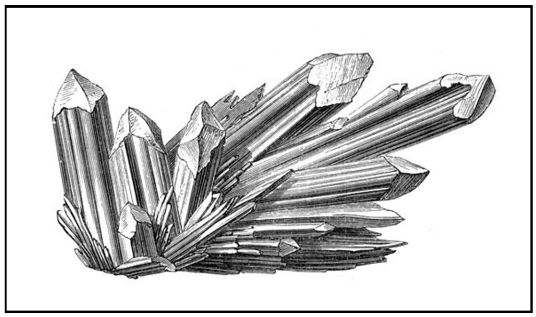


Topaz (Burat, 1864, Fig. 149)



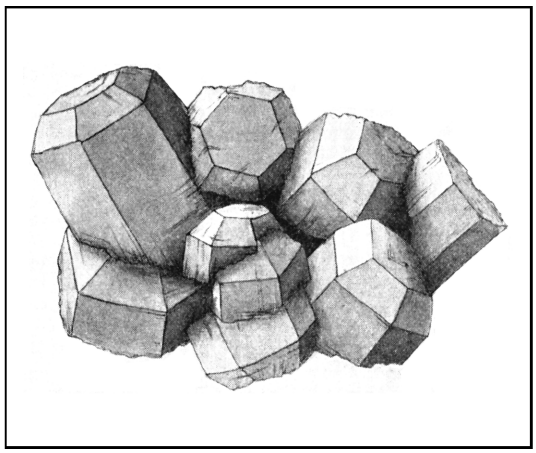
Silver (Burat, 1864, Fig. 183)

career spanning 43 years he retired as Professor Emeritus in 1881, and died two years later.



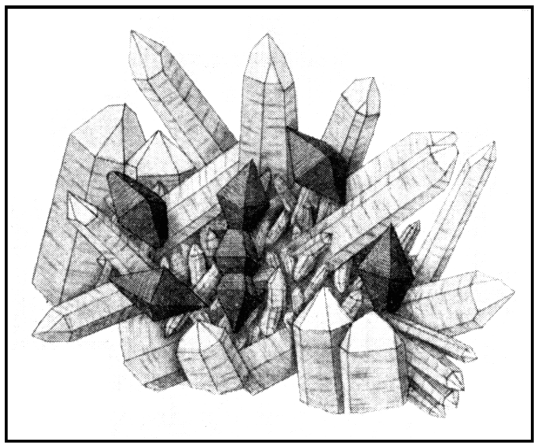
Stibnite (Burat, 1864, Fig. 193)

Burat's *Minéralogie Appliquée* (1864) contains dozens of fine steel-plate engravings of actual mineral specimens prepared by the well-known artist and engraver Hubert Clerget [1797-1867] from examples in unspecified collections particulaires ("private collections"). They are among the finest black and white depictions of mineral specimens ever produced by non-photographic means.

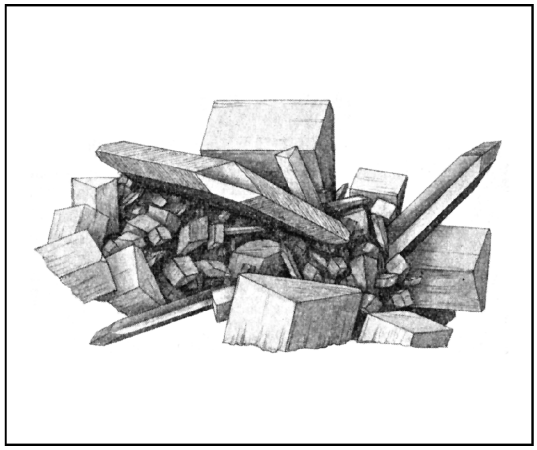


Apatite (Miers, 1929, Fig. 518)

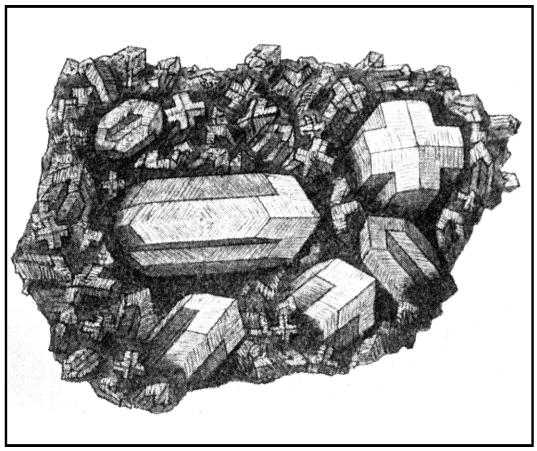
Contained in Henry Miers *Mineralogy* (2nd ed., 1929) are about one hundred very well executed black and white images of minerals. These are photographic reproductions of (black and white?) drawing executed by R.C. Spiller, who was the University Demonstrator in Mineralogy at Oxford. These are exceptionally well rendered non-colored mineral pictures, and show that specimen selection of sharp crystal form highlighted by shadows or by a contrasting mineral species of a distinctly



Anatase and Quartz (Miers, 1929, Fig. 548)

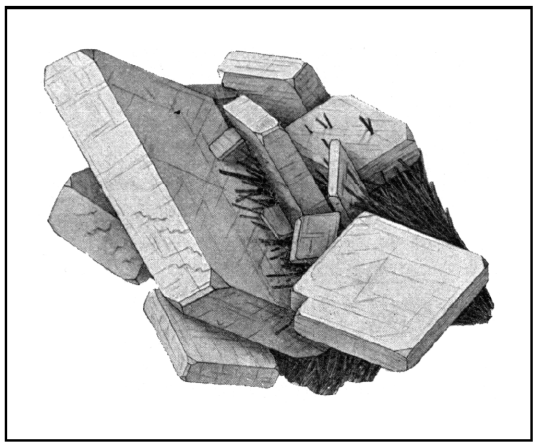


Titanite and Adularia (Miers, 1929, Fig. 540)



Harotome (Miers, 1929, Fig. 690)

different shape contribute greatly to the picture definition and recognizability.



Barite and Stibnite (Miers, 1929, Fig. 723)

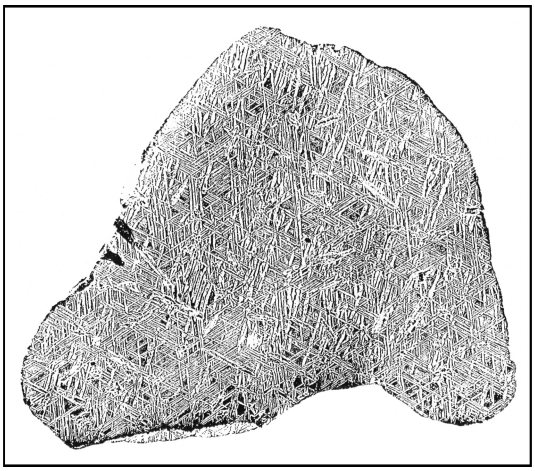
### 15.2.1 Printing from Actual Specimens[1659]

It was recognized in the eighteenth century that some natural history specimens could be used in the printing process to make their own illustrations. Plant leaves were especially good for this purpose because they could be pressed flat. In fact, the American inventor and printer, Benjamin Franklin used images of natural leaves as an anti-counterfeit method in the paper money he published for the early American colonies. This by passed the long tradition of requiring an artist to transfer an image to some medium that could be reproduced many times. Over time there were developed a series of technologies to reproduce images directly from the object in question. Although invented early on, and more common in botanical works, this method was used albeit rarely in mineralogical books to create realistic illustrations.

In a famous paper Alois Auer of Welsbach was the first to take note of this interesting set of publications that contain illustrations created from natural printing, or as he called it "Naturselbstdruckes" (nature self

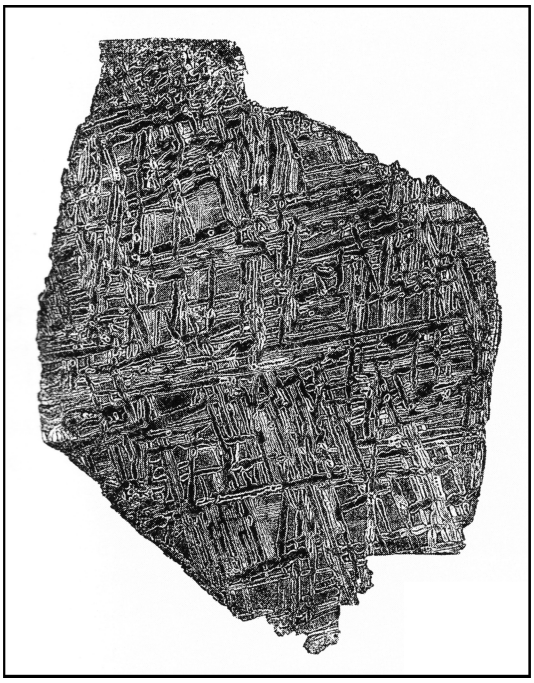
[1659] Further historical information may be found in: E. Fischer., "Zweihundert Jahre Naturselbstdruck, mit einer Bibliographie," *Gutenberg-Jahrbuch*, **8** (1933), p. 186-213. • Franz Kirchheimer., *Die Einführung des Naturselbstdruckes und der Photographie in die erdwissenschaftliche Dokumentation.* Hannover, Deutsche Geologische .Gesellschaft, 1982. 117 p., 43 illus. [Published as *Zeitschrift der Deutschen Geologischen Gesellschaft*, **133** (1982), this is a study of natural printing and photography in all of the earth sciences.]

printing).[1660] He provides a history of the development, a list of works that had illustrations created from the process, and a description of its use in botany and mineralogy. With respect to the later, he gives the term "Mineralographie" to mineralogical publications containing this type of illustration.



Meteorite Slice (Schreibers, 1820)

Karl Franz Anton Ritter von Schreibers [1775-1852] in his *Beyträge zur Geschichte und Kenntniß meteorischer Stein- und Metall-Massen* (1820) is the earliest work that used natural printing methods to render its illustrations of minerals.[1661] This slim volume, a landmark of the iconography of meteorites, features full size prints of various slices showing the characteristic Widmannstätten structure patterns. The lithographic plates number among the earliest products of natural illstration, and are considered to be "incunables of lithography," a process developed later in the century that used carved limestone blocks to create its pictures.



Meteorite Slice (Partsch, 1843)

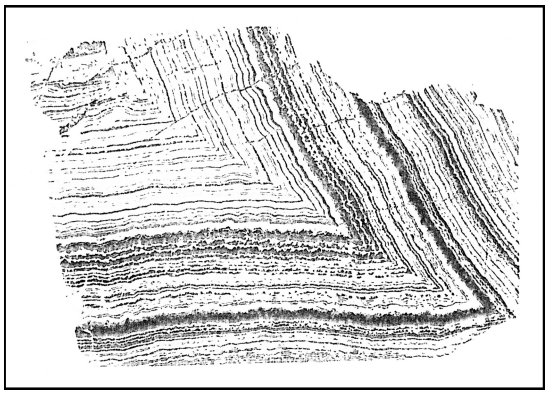
The *Die Meteoriten oder vom Himmel gefallenen Eisenmassen im k.k. Hof-Mineralien-Kabinette zu Wien* (1843) by Paul Partsch is the first scientific catalog of the Viennese meteorites collection. It is the richest and most complete in the number of localities it contains and was at the time the most complete collection of its type. Partsch lists 69 stone and 25 iron meteorites from different localities. He also supplies a good frontispiece illustrating the famous Widmannstattenschen pattern that is also another example of the natural printing of minerals.[1662]

Perhaps influenced by the etched meteorite slices, Franz Leydolt [1810-1859] proposed a new method of illustrating papers, provided the subject was a hard mineral containing quartz that could be sliced. In his paper on the banded agates of Germany, he published examples of

[1660] Alois Auer, "Die Entdeckung des Naturselbstdruckes oder Die Erfindung, von ganzen Herbarien, Stoffen, Spitzen, Stickereien und überhaupt allen Originalen und Copien, wenn sie noch so zarte Erhabenheiten und Vertiefungen an sich haben, durch das Original selbst auf einfache und schnelle Weise Druckformen herzustellen, womit man sowohl weiss auf gefärbtem Grunde drucken und prägen, als auch mit den natürlichen Farben auf weissem Papiere Abdrücke, dem Originale identisch gleich, gewinnen kann, ohne dass man einer Zeichnung oder Gravure auf die bisher übliche Weise durch Menschenhände bedarf," *Denkschriften der kaiserlichen Akademie der Wissenschaften. Mathematisch- naturwissenschaftliche Classe* (Wien, k.k. Hof- und Staatsdruckerei), **5** (1853), p. [6], 128, 22 colored plates.

[1661] Fischer, E., "Zweihundert Jahre Naturselbstdruck, mit einer Bibliographie", Gutenberg-Jahrbuch, 8, (1933), 186-213: no. 22. • Geus, Natur im Druck, 1995: no. 22. • Heilmann, Die Natur als Drucker, 1982. • Hlawatsch, Bibliothekskatalog, 1911: p. 263.

[1662] Fischer, no. 23.



Banded Agate (Leydolt, 1851)

natural printing of slices of banded agate.[1663] These were created by etching slices of the agate with acid and then electropating or otherwise create a casting of the etched surface, which can then be used to create the printing plate if the actual specimen is not to be used in the actual printing. He also suggests that the method could be used for publishing illustrations of other rock slices such as granite, but Leydolt's effort appears to be the only time this particular method was used in mineral illustration.

Even today some mineralogical specimens lend themselves to being used for print reproduction. The cover of the *Mineralogical Record* of the September/October 1975 issue was produced directly from a cleavage of transparent mica containing rutile crystals. The specimen was mounted as a 35mm slide that was then directly reproduced in color on to the printing plate for the cover of the issue.[1664]

Photography is of course a form of illustration that is taken from actual specimens. Its invention about 1839 and the subsequent technologies developed to reproduce the photographic image on the printed page illiminated the intermediate step of first creating a representation in some other material (i.e., a copper engraving). The first black and white photographic reproduction of minerals




Mineralogical Record (Sept./Oct., 1975)

occurs in the first volume of Alfred Louis Olivier Legrand Des Cloiseaux's *Manuel de Minéralogie* (1862, plate 5).[1665] It shows polished plates that are cross sections of six quartz crystals that show distinct zoning. The plate is reproduced from an early photograph. Although this appeared in the mid-nineteenth century photographic reproduction was a method that did not spread quickly. Most mineral books had illustrations created with the older technologies until the early part of the twentieth century.

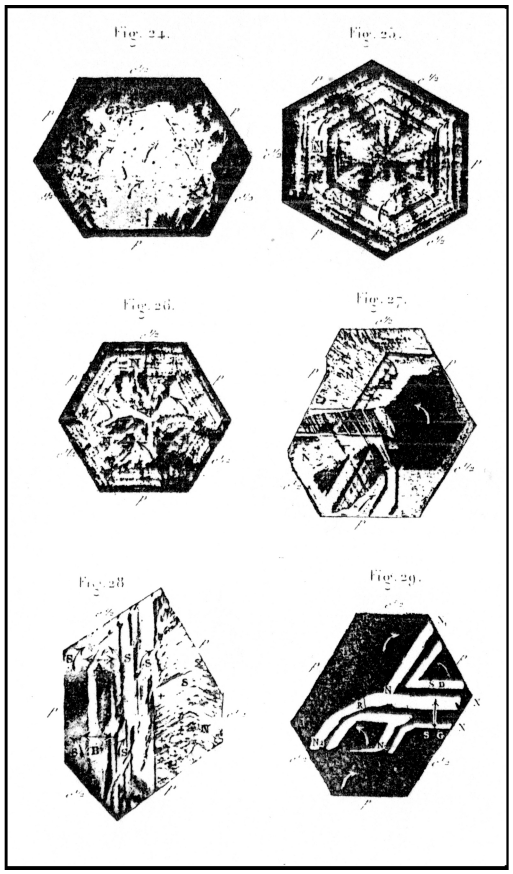
Color photographic reproduction was introduced in the 1882 book of Fouqué and Michel-Lévy on the synthesis of minerals and rocks *Synthèse des Minéraux et des Roches*. It is stated on the title page that the work contains "Planche en Photchromie" (Plates in Color Photos).[1666] The illustrations show the crystalline structure of rock underneath a polarizing light. There are probably other

[1663] F. Leydolt., "Eine neue Methode, die Achate und andere quarzhältige Mineralien naturgetreu darzustellen," *Jahrbuch k.k. geologische Reichsanst.*, **2** (1851), no. 2, p. 124-132.

[1664] *Mineralogical Record*, **6** (Sept./Oct., 1975), no. 5.

[1665] Franz Kirchheimer., *Die Einführung des Naturselbstdruckes und der Photographie*, 1982, p. 16-17.

[1666] Franz Kirchheimer., *Die Einführung des Naturselbstdruckes und der Photographie*, 1982, p. 85.




Des Closieaux (1862)




Fouqué and Michel-Lévy (1882)

examples of color photographic reproduction in the ninteenth century, but the next that has been found is the color photographic half-tone reproduction of a very fine rhodonite specimen that acts as a frontispiece to Louis Pope Gratacap's *Popular Mineralogy* (1912).

## 15.3 Minerals Illuminated in Colors

Thousands of illustrations of mineralogy and crystallography were published between 1469 and 1919, but the vast majority were monochrome, with black and white being the most economical method of reproduction. Only a small percentage of the renderderings were printed in color and only a fraction of these are done well. This section has a two-fold purpose. The first is an attempt to define the characteristics that create a good mineral illustration. The second is to describe the books that contain the best examples of colored mineral illustration, i.e., the most desirable colored mineralogies. Books containing color photographic plates have not been included, effectively ending this study in the first decades of the twentieth century. As a pointe of interest, color was introduced early in the history of printing, although it required a long time for technology to make it efficient. The first book printed in colors was the early astronomy work of Regiomontanus, Purbach & Sacrobosco, *Sphaera Mundi* that appeared in 1485.[1667]

[1667] Regiomontanus, Purbach & Sacrobosco., *Sphaera Mundi*. Venice, Erhard Ratdolt, 1485. 58$\ell$. This is Ratdolt's second edition (first 1482) of this collection which differs from first in having colors, new diagrams and Roman instead of Gothic letters. *Collation:* la blank; lb full-page figure of armillary sphere; 2a-18a *Sphaera Mundi* of Sacrobosco with 24 diagrams; 18b-44b *Theoricae Novae Planetarum* of Georg Purbach with 28 figs, in which colors are used in 9; 45a-58b *Disputationes Johannis de Monteregic* (i.e., Regiomontanus) *contra Cremonesia in planetarum theorica dileramenta*, with 7 diagrams.

The first is the astronomical work of John Holywood,

When attempting to build a library of finely illustrated books concerning mineralogy, a general axiom can be stated: Like choice mineral specimens, books containing good examples of mineralogical illustration are rare. One reason is rooted in the development of mineralogy and the people who undertook its study. It is not mere coincidence that almost all of the authors of early mineralogies were people with university educations. For many institutions, mineralogical studies were among the required course work to graduate with a degree. Therefore the persons most likely to have developed a sufficient interest in mineralogy to pursue its study and to publish books were university educated, upper class professionals and land owners. This is not to say that minerals were ignored by the uneducated, but compared to studies such as gardening or hunting, mineralogy had little practical value to people living off the land. As a consequence, while studies of plants and animals enjoyed tremendous popularity in the literature, relatively few individuals took interest in minerals, which meant a small market for publications about minerals, in turn meaning an even smaller market for expensive illustrated books.

Limited appeal undoubtedly contributed to the scarcity of fine illustrated mineralogies, but it is not the only reason. The interpretation of a physical form to a picture representation is by no means simple. Minerals have lustre, color, transparency, shape, weight and reflection, which all merge to make minerals the beautiful objects they are. Of these properties, color is perhaps the easiest to reproduce, but it requires an expert artist to convey the impression of the weight of a galena crystal or the iridescence of goethite in an illustration. Even using the truest of all renderings, the photograph, the physical qualities of a mineral are not easily shown. Imagine then the great difficulty before photographic reproduction, when all mineral books were illustrated by hand. Unless one is a collector, minerals and crystals tend to be outside the experience of daily life. This was also true in past centuries, which presented a great problem for the mineral illustrator.

All similar objects differ from one another to some degree. The pattern of stripes on one zebra is different from all other zebras, yet when one is illustrated, it is usually easy to identify. This is because the brain recognizes the characteristic shape of a horse, and classifies the distinctive coloring as belonging to a zebra. Pattern recognition is therefore used by the brain to isolate and classify illustrations. That is why early pictures of fish, animals, birds, and human beings are usually easy to recognize, whereas those of minerals commonly resemble only blobs of printer's ink.

Every mineral specimen is unique; even within the same species, minerals can have vast variations. The form of the matrix, the crystal shape, the associated minerals, and their arrangement all contribute to make each specimen singular; this greatly expands a problem found in other areas of natural history illustration. With every mineral specimen unique, it is difficult to create a drawing that will be recognized by an untrained brain as a mineral and even more difficult to create a picture that will be recognized by a mineral collector as a specific species. Additional problems and benefits result from the specific technique used to create the illustrations.

In preparing hand colored plates two procedures were used. The earliest one involved having the actual specimen being illustrated sitting in the center of a table surrounded by the colorists. The plates, previously imprinted with the outline of the specimen, were hand colored with the appropriate tints to approximate what the colorist saw. Illustrations colored by this technique have a wide variation in quality from plate to plate because each colorist had a slightly different view of the specimen and therefore a different perspective of the colors and reflections. To

of Halifax, who wrote this work in Paris in 1229. Purbach [1423-1461] the earliest 'modern' astronomer, studied in Italy. His *Theoricae* was first printed posthumously in 1472. The work of Regiomontanus (=Johannes Muller [1436-1476] of Konigsberg) is in form of dialogue with a 'man of Cremona' that is Gerard of Cremona [died 1187], translator of Ptolemy's *Almagest*. *Refs:* S.T. Redgrave., *Erhard Ratdolt and his work at Venice*. Illustrated Monographs No. I. London, Printed for The Bibliographical Society at the Chiswick Press, 1895. [8], 50, [5] p.

achieve better quality control a second method was introduced that overcame the perception problem. By creating a standard colored plate, the colorists were able to maintain high quality and produce in quantity. To make the standard, the chief artist would color one or more plates using the actual specimen as a guide. Then the assistant colorists would duplicate on their own uncolored plates what was on the standard. This procedure tended to produce a uniform quality of plate at a faster rate, and thus was the method that came into general use. Yet hand coloring was not universally accepted, and other less labor intensive methods of color printing were attempted.

Based on Newton's color theory, mezzotint printing was invented by Jacob Christophe Le Blon at the beginning of the eighteenth century. Believing that all colors could be produced from the three primaries – red, blue, and yellow, Le Blon made three plates for every print, each one representing one primary color of the finished plate. Now by inking each one separately, and then printing them successively in register, in the order, blue, yellow, and red, the colored illustration was created. Although this method required careful planning before the copper was engraved, there were no colorists needed and at times the plate quality was superior to the finest hand colored attempts. Mezzotint printing never achieved the acceptance of hand coloring, however, and it was not until chromolithography was invented that hand coloring faded.

Like mezzotint, chromolithography is a method that uses successive overprinting in different colors to build up a picture. The method for making the stones is the same as standard lithography, but instead of one stone, several are used. Each stone is designed so that like mezzotint printing, it represents a single color of the finished plate. A finished color plate is created by inking each stone with a different color, and overprinting in register on the same sheet of paper. The technique was first used around 1840 and within decades became the principal method for creating relatively cheap color illustrations. As the nineteenth century progressed, however, labor costs and the rising price of the particularly fine grained limestone needed caused the general decline of chromolithography. It was replaced by the three color process, which for practical purposes reproduces in a book any color photograph.

The great cost in creating a book with colored illustrations leads to another interesting feature of the early colored mineralogies. These books were usually not published by the volume, but by the section. Someone wanting a copy of, for example, Sowerby's Exotic Mineralogy in 1811 would arrange with Sowerby so that every two months or whenever they were published the subscriber would receive another section of the book. This section would contain on average ten pages of text and three hand colored plates. In order then for a book to be completed the subscriber would have to continue his interest as long as sections were published – decades in several cases. After a sufficient number of sections had accumulated the publisher would send out a title page and index and the subscriber would send his accumulated sections to a bookbinder, who would sew them together, and bind them in leather or cloth to suite the subscribers tastes and purse. Obviously, there was an excellent chance that a particular book would not be completed. If a volume was not well regarded, the subscriber would stop buying new sections or if there were not enough subscribers to justify continued publication, the work would never be completed. Unfortunately this was all too often the case with the early mineralogies, so fortunate is the collector who has complete copies of a rare colored mineralogy. Book Descriptions

The descriptions are arranged chronologically. The format adopted gives a brief biography of the author followed by a specific description of the book or books of interest. The complete title of any book described along with a collation of its pages and plates together with information about other editions is listed in the notes. It is believed that all the important colored mineralogies have been included, together with many that are obscure. This list is subjective based on volumes actually examined. No encyclopedias are listed, and all books

described are known to exist in more than one colored copy.

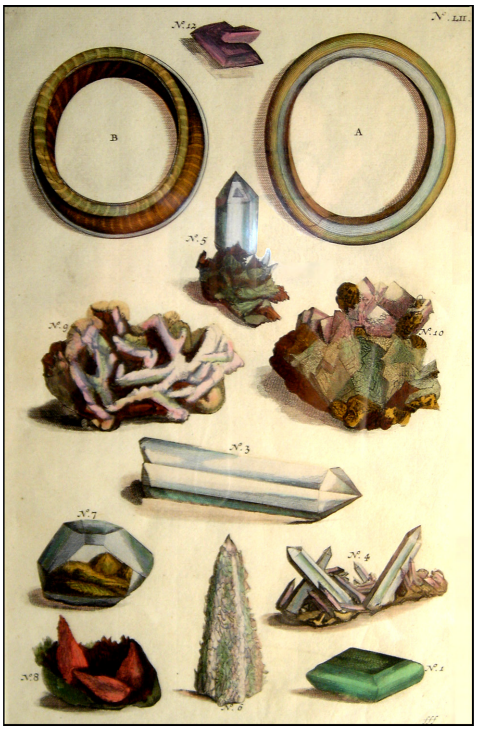
### 15.3.99 Rumpf

The first book published with hand-colored plates showing minerals was published in 1705. Georg Eberhard Rumpf (or Rumphius) [1637-1706], the blind "Plinius Indicus", had been in the service of Dutch East-India Company as merchant and was stationed at the Island of Ambon in the modern day Malay Archipelago, Indonesia, where he started researching systematically the natural history of this island. He described and drew all he saw and sent his manuscripts and collections back to Amsterdam. These included specimens of the plants, animals, and minerals of the region. On his return to The Netherlands, he used this information to compile his most famous work *D'Amboinische Rariteitskamer*, which was published a year before his death in 1705. It contains his collected observations on the natural history he observed and is illustrated with 60 magnificent copper engravings of the specimens he collected. These plates may be separated into the following categories: crabs (12), sea-urchins & starfish (4), snails & muscles (33), and petrifications and minerals (11). There is also an engraved title page, a beautiful engraved frontispiece portrait showing Rumpf and 4 engraved vingettes. The work is especially interesting as it shows the contents of a typical cabinet of natural curiosities of the early 18$^{th}$ century, very popular at the time, and the forerunner of the museums of today. It also exhibits Rumpf's amazing talent as a naturalist, because although he was in a faraway land, removed from every center of intellectual civilization he was not totally isolated. His text shows that he corresponded with many scholars in the Indies and Europe like Rhijne, Cleyer, Mentzel, Valentini, etc.

Copies of the work are almost always found with uncolored plates, and for a very long time, only one copy of the book was known to contain colored plates. It is an extraordinary natural history volume held in the collection of the Library of Artis, Amsterdam. The copy had been colored by the famous naturalist, Maria

**Colored Mineralogies**

| Year | Author | Mineral Plate Count |
|---|---|---|
| 1705 | **Rumpf** | 11 |
| 1732 | **Richter** | 61 |
| 1734 | **Seba** | 4 |
| 1734 | **Hebenstreit** | 17 |
| 1748 | **Hill** | |
| 1753 | **Schmiedel** | 42 |
| 1754 | **Knorr** | 6 |
| 1754 | **Wirsing** | 100 |
| 1769 | **Stieglitz** | 21 |
| 1774 | **Walch** | ? |
| 1775 | **Ledermüller** | |
| 1776 | **Gmelin** | |
| 1776 | **Hamilton** | 6 |
| 1779 | **Guettard** | 19 |
| 1779 | **Schultz** | 1 |
| 1781 | **d'Agoty** | 70 |
| 1781 | **Uibelaker** | |
| 1781 | **Wünsch** | 16 |
| 1782 | **Buc'hoz** | 100 |
| 1785 | **Wulfen** | |
| 1787 | **Klaproth** | 1 |
| 1789 | **Karsten** | 5 |
| 1789 | **Spalowsky** | 4 |
| 1790 | **Bertuch** | |
| 1794 | **Baumeister** | |
| 1794 | **Lenz** | |
| 1797 | **Rashleigh** | |
| 1801 | **Patrin** | 40 |
| 1804 | **Sowerby (British)** | 550 |
| 1809 | **Egypt** | 4 |
| 1811 | **Sowerby (Exotic)** | 179 |
| 1812 | **Mawe** | 2 |
| 1832 | **Stephenson** | |
| 1834 | **Wilhelm** | 132 |
| 1842 | **Schriften** | 2 |
| 1843 | **Oken** | 2 |
| 1850 | **Schmidt** | 44 |
| 1850 | **Sowerby (Popular)** | |
| 1858 | **Kurr** | 24 |
| 1867 | **Reynaud** | 2 |
| 1867 | **Simonin** | |
| 1871 | **Weber** | 64 |
| 1873 | **Hamlin (Tourmaline)** | 4 |
| 1890 | **Kunz** | 2 |
| 1895 | **Hamlin (Mount Mica)** | |
| 1903 | **Brauns** | 73 |
| 1907 | **Leteur** | 26 |
| 1914 | **Pogue** | 1 |
| 1914 | **Artini** | 40 |



Rumphius, 1705



Rumphius, 1705

Sybilla Merian, as is recorded on the half title by a former owner A. Vosmaer [1720-1799], the director of the princely zoological gardens at Het Klein Loo near The Hague. In fact, it is now generally assumed that all of the plates for Rumpf's book were designed by this famous woman naturalist, who was one of the greatest illustrators of natural history of the day.

Maria Sybilla Merian [1647-1717] was highly interested in flowers, insects and other aspects of nature, especially those which came from exotic locales such as Rumpf's Surinam specimens. So it would be no surprise to discover she had taken an interest in Rumpf's work, and helped with its preparation for publication. In any event, it is clear she had access to the Rumpf's specimens, because the coloring of all the plates is very accurate, and done with an expert hand. The German traveller and burgomaster of Frankfurt Z.C. Von Uffenbach [1683-1735] visited Merian in Amsterdam on February 23, 1711. He recorded this visit enthusiastically in his diary, which was published in 1753-54. It was during that visit he mentions seeing a copy of the *d'Amboinische Rariteikamer*, superbly colored and printed on large paper, which he considered one of the most beatiful books he had ever seen. Later in the 18th century, the noted German book collector Joseph Cobres could also boast to having a colored copy of the 1705 edition in his library.[1668] So coveted were these few colored copies that in 1779 at an auction the Vosmaer copy fetched FL. 240, which was a serious amount of money for a book at that time (a good house could be purchased for a quarter of that amount!).

In 1997, a complete hand-colored copy of the Rumpf book appeared on the market, which was compared to the Vosmaer copy by the bookseller and found to be identical.[1669] The confluences of good specimen material

[1668] J.P. Cobres, *Deliciæ Cobresianæ*, 1782, p. 103. His copy had the title page and all the plates including the frontispiece showing Rumpf hand-colored. He purchased the copy at the Bozenhard Auction, noting its great rarity in a colored state. • J.S. Schröter., *Journal für die Liebhaber*, **6** (1780), p. 395.

[1669] H.L Stack and J. Goud, "Rumphius and the 'Amboinische Rariteitkamer'," *Vita Marina*, **44** (1996), nos. 1-2, p. 29-39. [Describes a recently found colored copy of Rumpf's book.]

and exceptional execution by a highly talented artist combine in these rare colored copies to make perhaps the most beautiful colored mineralogical plates ever produced, not to mention exceptional renderings of shells, crabs, and other objects of the cabinet. Unfortunately, it is also perhaps the rarest of the colored mineralogies with only the two complete copies and an unknown but small quantity of loose plates currently known to exist.

### 15.3.99 Richter

A self-described 65-year old mining expert and inspector of precious stones by appointment from the Elector of Saxony, Christian Richter [1678-1732] published his *Saxoniæ Electoralis Miracvlosa Terra* (1732) at his own expense and dedicated the book to King August II of Poland. This rare work is also known in a few rare copies to contain hand-colored illustrations. The text describes and illustrates mineral and rock specimens from the mining region of Saxony. In particular, Richter describes several samples of "Wundererde," which is a colorful variety of jasper found near Zwickau and is a stone used for ornamental purposes. The 61 copper engravings contained with in the text show in the form of cross-sections examples of this jasper and various ores with embedded minerals. Each image is carefully labeled with letters and referenced to the descriptive text. Although uncommon, in some copies these illustrations have been carefully hand-colored in watercolors and gouache to create beautiful depictions. Wagner (1902), who believes the illustrations to be a fantasy of the artist, records that the original paintings of the illustrations were held in the collections of the Mineralogische-Geologische Museum in Dresden at the beginning of the 20th century.[1670]

### 15.3.99 Seba

Albertus Seba [1665-1736] was born a peasant without fortune or prospects. The



Richter, 1732 (uncolored)

master of the village school noticed his eagerness to learn, however, and gave him instruction in Latin and all else he thought useful. After benefiting from these lessons, Seba was able to become an apprentice to an apothecary in Neustadt-Goedens, a town near his birth place. After his apprentiship, Seba moved to Amsterdam, where he found work in the flourishing pharmaceutical industry. Through connections he made there, Seba was offered the opportunity to travel abroad. He made two profitable voyages acting as agent for the famous Dutch East-India Company. Upon his return from the second venture, he settled in Amsterdam, where he married and established his own successful apothecary shop.

*Locupletissimi Rerum Naturalium Thesauri* (Amsterdam, 1734-65). This magnificiant work, commonly called Seba's Thesaurus, is a well know illustrated natural history, which in its colored form, is one of the most sumptous and complete records of any 18th century rariteitkammern. Its purpose was to describe and picture the natural history of the known world. The 449 plates (175 double-page) by P. Tanjé, A. van der Laan, F. de Bakker, A. van Buysen jun., De La Croix, J. Folkema, W. Jongman, F. Morellon, K.D. Pütter, J. Punt

[1670] Paul Wagner., "Die mineralogisch-geologische Durchforschung Sachsens in ihrer geschichtlichen Entwicklung," *Sitzungsgerichte und Abhandlungen der Naturhistorischen Gesellschaft Isis in Dresden*, 1902, p. 63-128.



Seba, 1734

and J. van der Speyk show specimens from all branches of natural history including some minerals and fossils often in fantastic if not bizzare groupings. It was the product of the golden age of Dutch bookmaking, and it is one of its greatest examples.



Seba, 1734

The text is known in two issues. The most common being Latin with a parallel French translation and the rarer issue consisting of the same Latin but with the French text being replaced by one in Dutch. The commentary describes in an unscientific though complex method Seba's arrangement of the specimens in his museum. However, it is not the text that makes this work desireable, but the astonishing and numerous plates depiciting at natural size many thousands of individual natural history specimens contained in the collection. The first volume describes and illustrates various leaves, fruits, roots that have been dissected to illustrate their internal structure, strange and exotic plants, rare animals most notable being the winged species of dogs, cats, rats, mice, squirrels, beautiful birds from the East and West Indies together with their nests, exotic snakes, lizards, crocodiles, iguanas, chameleons, salamanders, rats, mice, toads and frogs. The second volume shows a variety of extraordinary snakes, adders, lizards together with their anatomical structure, collected from different parts of the world. Also included are descriptions of various fossils and exotic plants. The third volume deals primarily with marine treasures such as beautiful shells, conches, starfish, marine plants, corals, sea spiders, sea mosses. The final volume depicts rare insects gathered from all corners of the earth as well as many varieties of precious minerals and ores and petrified wood.

Seba's early studies had given him a taste for natural history, and using the large fortune he had accumulated by his earlier travels he began collecting natural history specimens. He built a remarkable collection that became famous throughout Europe. Upon its merits, Seba was elected to membership in London's Royal Society, the Imperial Academy of Vienna, and other societies. In 1716, when Russia's Peter the Great [??-??] visited Amsterdam for a second time, he purchased the museum for the tremendous sum of 15,000 guilders and removed it to St. Petersburg, where it became the nucleus of a natural history collection in that city's academy of science. However, Seba could not contain his desire to collect, and so he embarked almost immediately on forming another collection, which by many accounts outshown his first effort within a few years.

As an apothecary, Seba was among the first to board ships newly arrived from overseas to sell and dispense medicines to the sick and exhausted crews. During this time, he would enquire as to what curiosities they had brought back from their voyage, and many times this would allow Seba to make a quick purchase. Duplicate items were then resold to his fellow

collectors for profit. Seba elected to perserve a memory of this collection for posterity and embarked after a time to prepare an elaborate illustrated catalog.

Seba seems to have written the basic text for the first volumes of the Thesaurus in Dutch, but he died in 1736 before all the volumes had been completed. Thereafter many other authors would have a hand in the works completion. The most important of these were P. Artedi [1705-1735] who wrote the descriptions of the fishes, P. van Musschenbroek [1692-1761] and H.D. Graubius [??-??]. Engel (1937) reproduces the agreement between Seba and the two firms of booksellers mentioned in the initial imprint and Landwehr (1976) provides a highly interesting translation of the original prospectus for the work. From these two researchers it can be said that Seba and the publishers were each to pay one third of the costs and after some concessions to Seba for providing the copy, they would equally share the profits. The work was published at 40 guilders a volume plain and 200 guilders colored. With Seba's death in 1736, and only two volumes thus far published and volume three only partialy complete, the work seemed destined never to be finished.

Only through the attention of Seba's son-in-law, Van Ommeting was the work carried through. But in order to pay the remaining publication costs, Seba's fabulous museum which upto that time had remained intact had to be auctioned. This occured sixteen years after Seba's death on 14 April 1752 and subsequent days. The entire sale realized 24,440 guilders (Engel, 1961), more than enough money for the Thesuraus to be completed.

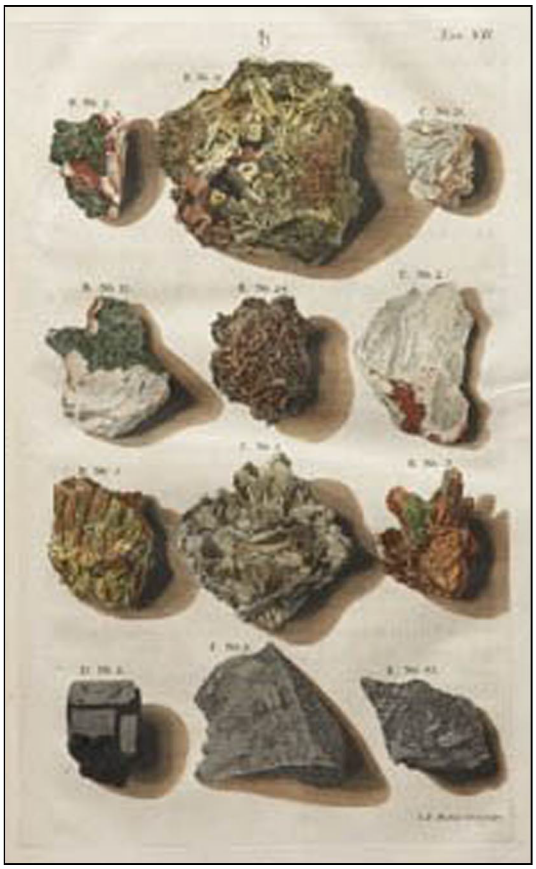
Of mineralogical interest are plates 100-103 of volume four. Here are depicted over 100 mineral specimens, many of them fine examples and obviously the product of careful selection. They are mostly metallic species containing gold, silver, mercury, iron and copper. The golds came from Sumatra, Japan, Hungary, Borneo, Siam, Cuba, Ceylon and New Spain. The silver and silver ores are listed as coming from Norway, Japan, Guinea, Germany, Siam, Hungary, Arabia and Virginia. As Wilson (1994) points out, Despite its relatively small size and clearly subsidiary status amid his much vaster array of plant and animal remains, [Seba's] mineral collection was suprisingly sophisticated and broad–based in its range of localities.

### 15.3.99 Hebenstreit

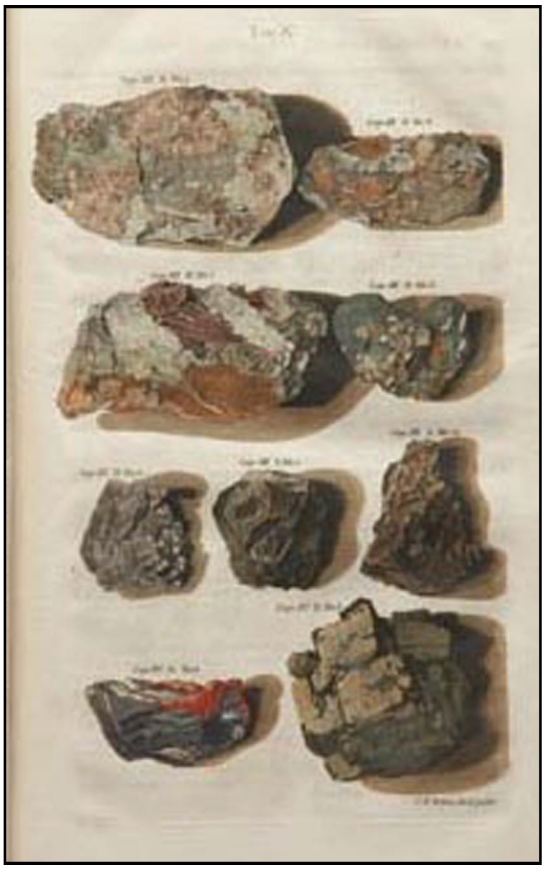
Johann Ernst Hebenstreit was born January 15, 1702 at Neustadt an der Oder, Germany. As a youth he became interested in natural history, preferring most of all botany. In 1723 he entered the University of Leipzig to study medicine, eventually becoming a professor there in 1730. At the request of Saxony Prince Friedrich August II, Hebenstreit made a scientific expedition to North Africa in 1733. After these travels, however, he returned to his professorship at Leipzig, where he continued to write on medicine and natural history. Hebenstreit died at Leipzig, Germany December 5th, 1757.

Among Hebenstreit's writings is a description of a large mineral collection. This catalog published at Leipzig in 1743 has the title, *Museum Richterianum*, and is a lavish volume describing the mineral cabinet of Johann Christoph Richter, a wealthy Leipzig collector. The text, written in both Latin and German, was authored by Hebenstreit, and describes all aspects of mineralogy. But it is the seventeen very fine engraved plates, all prepared by the Leipzig-born engraver and watercolorist Christian Friedrich Boetius [1706-1782], that are the attraction of this book. The frontispiece (i.e., a plate directly opposite the title page) shows a portrait of Richter, the second a double page of the interior of the museum, and the remaining seventeen illustrate various minerals, metals, fossils, and gems from the collection. Although this book is more commonly encountered with plain plates, a very few copies exist where the illustrations have been beautifully and very realistically hand colored.

The extraordinary accuracy of the coloring – the gold nuggets really look like gold nuggets – could only have been accomplished if the unknown colorist had access to the actual specimens from Richter's collection. Perhaps the coloring can also be attributed to Boetius,



Hebenstreit, 1743



Hebenstreit, 1743, Plate 10

but in the four copies so far examined there is no indication whether this assumption is correct. In fact, because so few copies of this work are colored, many book collectors and bibliographers don't realize that such copies exist.[1671] Generally speaking, the plates of the colored copies are produced on a heavier paper, which is accompanied in most cases with the text printed on a thicker paper as well. In short, colored copies tend to be noticeablly thicker books than the uncolored copies.

### 15.3.99 Hill

John Hill is thought to have been born in 1707 at Peterborough, England. Turmoil largely characterizes and surrounds Hill's life and accomplishments. Early on he was apprenticed to an apothecary, eventually taking up the profession himself. In an attempt to increase his income he published a number of ill received studies concerning the medical properties of plants. Hill did not accept this rejection however, and with these publications he started a literary career that can only be described as voluminous. His writings however frequently caused controversy among his contemporaries, which caused many scathing attacks to be published about and by Hill in the journals of the day. On being refused membership in the Royal Society of London, Hill began a campaign of ridicule, which culminated in his satirical 1751 work, A Review of the Works of the Royal Society. To further enrage English society, he began calling himself Sir John on account of the 1774 award by King Gustav III of Sweden of the Order of

[1671] For example, the eighteenth century book collector Joseph Banks did not own a colored copy. His contemporary, Joseph P. Cobres, whose library specialized in natural history works, especially colored ones, apparently did not even know colored copies existed. *Cf.* Cobres, *Deliciæ Cobresianæ*, 1782, p. 110. None of the standard bibliographies make mention of colored copies either.

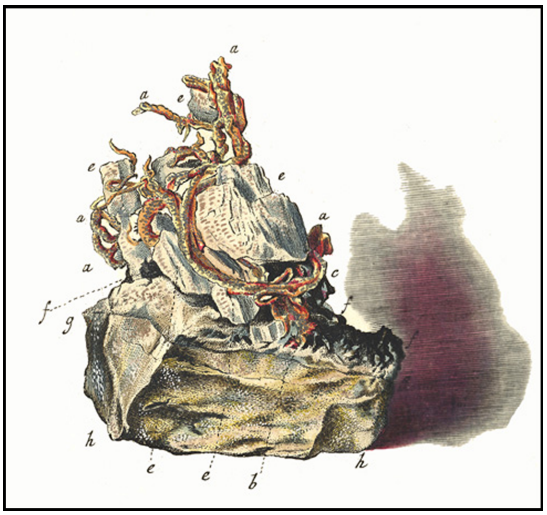
Vasa. Hill died the 21st November, 1775 in London, England, after a life which saw the publication of literally hundreds of books and papers and a vilification of his name which lasted long after his death.

Among several mineralogical works authored by Hill is *A General Natural History ... Volume One ... A History of Fossils*, which was printed at London in 1748. This thick folio is perhaps best remembered as one of the earliest attempts at a systematic mineral nomenclature. The author divides the minerals, including fossils, into numbered series, classes, and orders, giving under each the genera and species. The minerals are then described according to their behavior in fire and acid, their cleavage or lack thereof, their surface texture, and their appearance under the microscope. Hill's odd scheme for naming minerals is now applied. Based in the Greek language, every name is derived from the physical characteristics of the mineral. A good example of a mineral named by this method is Pyricubium maximum foliaceum for a pyrite cube, striated. Happily, the system never came into general use, and Hill himself adopts a much simpler one in his other mineralogical works. The book is important however, in the history of illustrated mineralogies.

A History of Fossils was the first of a three part series concerning the three kingdoms of nature: minerals, plants and animals. Because of its uncommon terminology, the mineralogy volume was widely criticized and quickly ignored, while the other two volumes enjoyed widespread popularity. The first volume of the set however was the first book in literature to use the hand coloring of mineralogical subjects on a large scale. This is not to say that all copies of Hill's History contain colored plates. A note on the back of volume three's title page states: There are a small number printed for the curious on Royal Paper; and the cuts of these are colored under the immediate inspection of the author. The plates show a great variety of items, including crystal types, selenites, rocks, and fossils. The illustrations are very good for their early age, and with coloring they are made very realistic.

### 15.3.99 Schmiedel

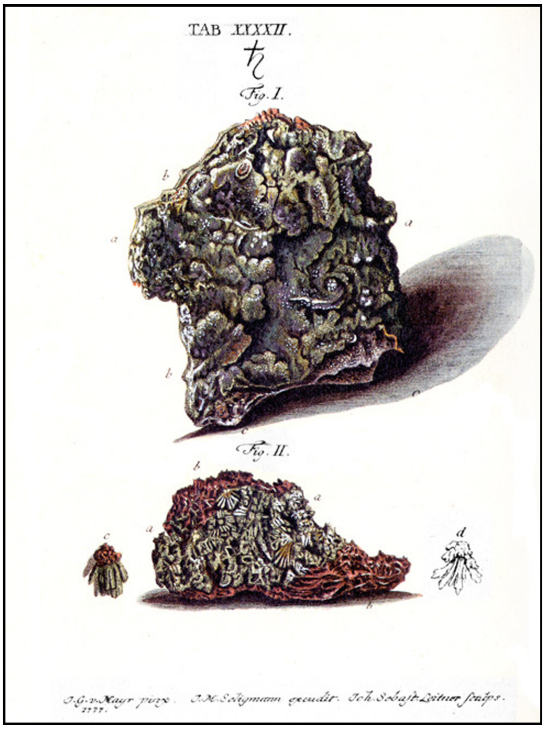
Casmir Christoph Schmiedel was born to the family of the Brandenburg financial councillor on November 21, 1718 at Bayreuth, Germany. Due to the untimely death of his parents, he left Bayreuth in 1728, spending the next several years traveling among relatives. Eventually, Schmiedel matriculated in medical studies at the University of Jena, and later continued his studies at Halle, where he received his M.D. in 1742. It was sometime during his education that Schmiedel took up on his own the study of natural history. After graduation Schmiedel found rapid success becoming a professor at Erlangen and establishing a successful private medical practice. Eventually, this lead him into a succession of positions in the state government and the Brandenburg court. He died at Ansbach, Germany on December 18, 1792.



Silver (Schmiedel, 1753)

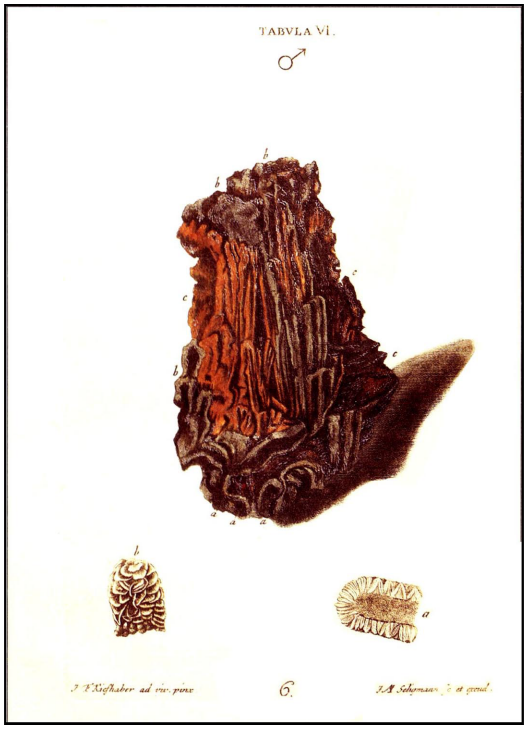
Although Schmiedel's best known books concern botany and medicine, he did manage to publish one work of mineralogical interest. Written in both Latin and German with up to 46 hand colored plates, this volume has the title, *Erz Stuffen und Berg Arten mit Farben genau abgebildet* and was published at Nurnburg in 1753. The author intended his work to illustrate various valuable ores in their exact colors, so that miners and prospectors could use it as a handbook to locate rich veins.

A noted Nurnburg engraver, Johann Michael Seligmann, working under Schmiedel's exact instructions, was responsible for the plates, which show various ore specimens of copper, lead, zinc, silver and gold. Unfortunately, no crystallized examples are shown which might cause one to downgrade the importance of the book. This should not be the case, however, because this work, the first illustrated field guide in mineralogy, achieves its purpose of accurately illustrating samples of various ore minerals.




Pyromorphite (Schmiedel, 1753)

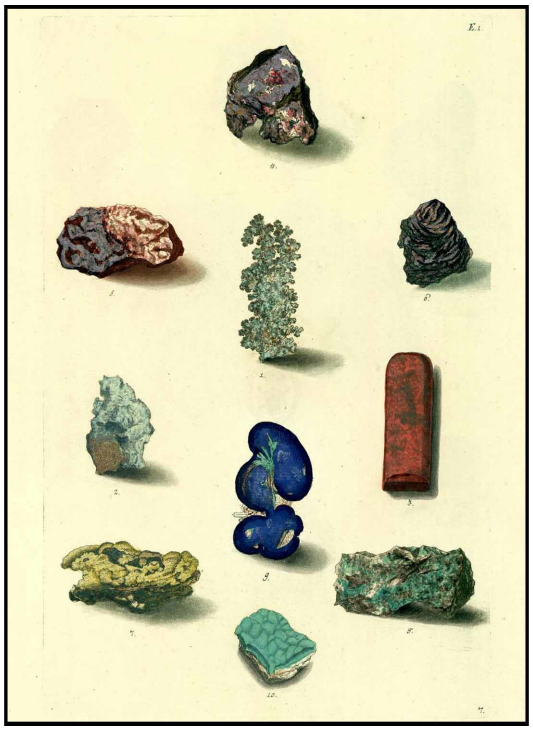
As happened with many colored mineralogies, Schmiedel was never able to complete the book to its original design. The prospectus for Erz Stuffen und Berg Arten announced that new sections containing 3 plates were to be issued every 2 months. However, due to an insufficient number of subscribers, the flow of new descriptions and plates became erratic, and with only twenty-eight plates distributed, eventually was suspended in 1765. At this time though, Schmiedel's book was greatly admired and was being used throughout the mines of the German states as a practical tool. Thereafter, the author was understandably deluged with requests to continue publication. Yet not until after 1771 were any new descriptions or plates issued. Then sections again began to appear until a total of forty-two plates were issued. Publication then again appears to stop because the standard bibliographic references consider copies of this book to be complete with forty-two plates. There exist, however, a few copies with descriptions and four additional plates, thereby totaling 46 plates. Since the added plates do not identify their engraver or year of creation and are numbered so that they are added at the end of the volume, it is assumed they were issued at some later time, and therefore included in only a few copies.




Copper (Schmiedel, 1753)

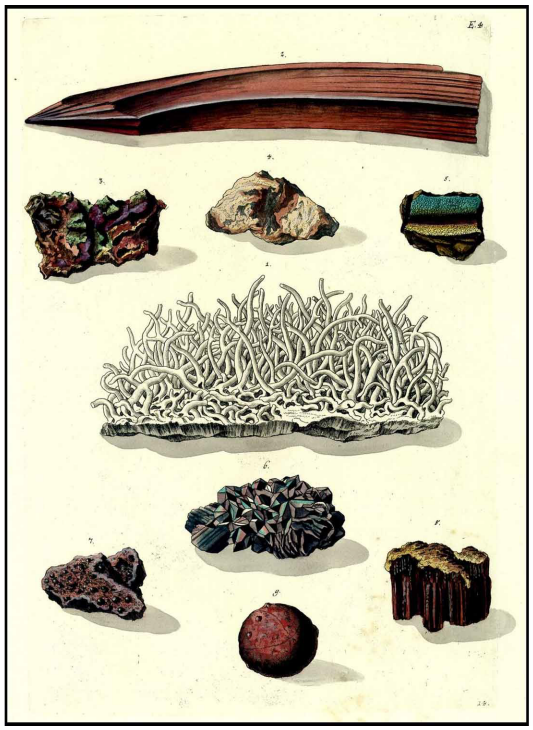
### 15.3.99 Knorr

Georg Wolfgang Knorr [1705-1761], was a German paleontologist, painter, engraver and art dealer. He engraved portraits, landscapes and animal studies after Dürer. In the 18th century, Nuremberg became the leading city in the production of fine illustrated natural



Knorr, 1754

history books. This was due to the stimulus of J. Trew, a wealthy Nuremberg physician, who assembled a number of artists and scientists around him. This circle included Knorr himself, as well as J.F. Dietsch, J.C. Keller, C.N. Kleemann, C. Leinberger, A. Hoffer, J.A. Eissenmann and J.F. Schmidt. They contributed to the drawings, engravings and hand-coloring of the plates of the *Deliciae Naturae Selectae*. Trew owned a natural history collection and menagerie. Many animals and curiosities described and depicted in the work originated from his collection, indicated by "Ex. Museo Excell. D.D. Chris. Jac. Trew" at the bottom of each plate. But there are also contributions from other natural history collections made by P.L.S. Müller, D. Schadeloock, Knorr himself and others. The plates depict a variety of natural history objects as follows: corals and seaweeds 15 plates, shells 7, butterflies 6, urchins 4, minerals and metals and sea anemones 6, crustaceans and spiders 7, starfishes 4, fishes 9, birds 7, quadrupeds 14, reptiles and amphibians 12. The accompanying text is contemplative, anecdotal and not scientific. An extensive list of references to naturalists of the 16th-18th century is given, including Linnaeus, but his system is not followed. The *Deliciae Natureae Selectae* was published in German and French in 1754 to 1767 and translated into Dutch in 1771 by P.L.S. Muller. There is a subscribers list in the Dutch edition containing 91 names for 99 copies.



Knorr, 1754

Knorr was also involved in creating the plates for the famous *Recueil De Monumens Des Catastrophes que le Globe de la Terre* (1768), which is the most complete account of the fossils known in the 18th century. Working in conjunction with Johann Walch, who authored much of the text, Knorr decided to prepare a complete treatise on the subject of fossils with the aid of specimens contained in the numerous collections of Germany. Knorr, however, only lived long enough to complete and publish the first volume, though he left a lot of material for the rest of the work. Walch ... a keen geologist ... was persuaded to carry on the work of Knorr ... The work contains a masterly and exhaustive account

of all the paleontological knowledge that had been acquired up to that time. Unfortunately, there was little of mineralogical value published in the work, the only plates being of some beautiful dendrite formations.



Knorr and Walch, 1775

### 15.3.99 Wirsing

*Marmora et adfines Aliquos Lapides* is a highly attractive book describes and illustrates specimens of ornamental marble, and provides mineralogical details of occurrences in locations throughout Germany. Unlike the present day meaning, the word marble during the late eighteenth century referred to any stone that could be cut and polished for decorative purposes; therefore, it is not surprising that each plate of this work illustrates from 4-9 rectangular tablets of polished stone. The spectrum of colors and patterns inherent in natural rock is accurately reflected in the fine hand-colored plates, which exhibit an extraordinary range of patterns of color in their figures. The specimens are classified according to the locality from which they originated and numerically keyed to the text. This original edition appears to be the scarcer of the two published editions, perhaps indicating that the remining uncolored plates were incorporated into the Amsterdam edition.



Wirsing, 1775

*Afbeelding der Marmor Soorten* is a true polyglot edition with 100 brilliant, hand-colored plates of marble specimens from all parts of Europe is one of the finest works to come from the Amsterdam scientific publishing firm of Jan Christian Sepp. The work was originally issued in 10 parts each covering a different part of Europe where marble was quarried. The number of examples on each plate ranges from 2-9 and these are numerically keyed to the text written by the German naturalist Casmir Christoph Schmidel, which is set in four parallel columns (Dutch, German, English, French), with the Latin below. Careful examination reveals the intrigue patterns printed on the plates that were used by the colorist in applying the color wash. In every case, the individual specimens are shown in a squarish-rectangular format, with shadowing giving the plates a three dimensional

appearance, and a colorful almost abstract look.

This is the only Amsterdam edition, which utilizes some of the same plates as the original Nürnberg edition of 1775 [see previous entry], as indicated by the signing of "A.L. Wirsung exc. Nor." Side-by-side comparison of the two editions suggests that these plates were printed in Germany but probably colored in Sepp's publishing house. The most complete collation of this work calls for 100 plates, which includes a supplement of 6 plates, with the text describing entries upto Tabula 75 only. Copies in this state are exceptionally rare. Landwehr also calls for a frontispiece which was missing from the all copies examined for this entry.

First edition with a large number of plates of this extremely rare work on marble with spectacularly coloured illustrations of 417 cross-sections of marble. The work was published in parts. The depicted stones in Marmora et adfines Aliquos Lapides are called "marble," however not all stones are "the granular/crystalline metamorphic rocks normally considered to be marbles but they include numerous very fine-grained types that probably are limestones, many veined, others spotted, and still others brecciated, and including fossiliferous varieties. In some examples the banding suggests that these are calcite onyxes or possibly several cut from cave onyxes" (Sinkankas). "Under each painting lies a complex, lightly-incised network of lines, almost like rouletting, over which the coloures have been laid. Near the end of the volume appear the most complex designs, beautifully done, of slabs of dendritic limestomes" (Sinkankas). The depicted stones come from quarries in or near Bayreuth (13 plates), Würtemberg (12 plates), Neresheim (5 plates), Durlach (6 plates), Salzburg (6 plates), Switzerland (7 plates), Baden (3 plates), Tyrole (2 plates), southern France (6 plates), Brabant (8 eight plates) and Saxony (5 plates). There are two, four, six or nine numbered samples to a plate, accompanied by text-leaves with an explanation in Latin (left column) and German (right column). The text-leaves are paginated consecutively. Adam Ludwig Wirsing (1733/34-1797) was an important engraver of natural history works, but the present, splendidly drawn and coloured work is not mentioned by Thieme & Becker. The text was provided by Casimir Christoph Schmidel (1718-1792.




Steiglitz, 1769

### 15.3.99 Stieglitz[1672]

Christian Ludwig Stieglitz [1724-1772] was educated at the University of Leipzig, obtaining an advanced degree in jurisprudence. He held several high positions in the city government of Leipzig. In 1754 he married Christiane Richter, daughter of Johann Christoph Richter, the founder of the "Museum Richterianum" in Leipzig, described and illustrated by Hebenstreit in 1754. In 1765 Christian and his two younger brothers were appointed "Nobles of the Empire" in Bohemia. They had a son of the same name [1756-1836], who became a prominent art historian and architectural archeologist.

[1672] W.E. Wilson., "Preface to the new edition," in C.L. Stieglitz, *Specimens of Some Natural Things from Underground in a Leipzig Collection*, a facsimile reprint by Mineralogical Record, Tucson, 1992. 88 p.

It is not known when he became a collector of minerals, perhaps it was when he was visiting his future father-in-law's fine collection. In any event, Stieglitz' collection came to the attention of the mineralogists of the time. For example, Cronstedt made a brief notice of it. Perhaps to make knowledge of its existence more widespread or perhaps as a method for enticing a buyer, Stieglitz published his *Spicilegium Quarundam Rerum Naturalium Subterranearum* in 1769, which describes and beautifully pictures 68 of his finest specimens. This slender volume, published anonymously but with the dedication signed by Stieglitz, is an extraordinarily fine example of an illustrated mineralogy. Each of the twenty-one plates show one or more fine crystallized specimens, of which perhaps the most notable are the wire silvers and calcites from the mines of Saxony. The accompanying text describes the figured specimens in both Latin and German. The plates are also known in two states: plain and hand-colored. Due to the rarity of the book (12 copies currently known, of which 7 are hand-colored), it is likely that it was intended for only a small distribution. According to Frieseleben (1828) the plates were designed and probably colored by a miniaturist artist by the name of Morino (about whom nothing more is known).[1673]



Acanthite and Calcite (Steiglitz, 1769)

After Stieglitz' death, a sale catalog for his minerals was prepared, *Vollständiger Catalogus einer Suiten Mineralien-Sammlung*



Silver (Steiglitz, 1769)



Cassiterite and Quartz (Steiglitz, 1769)

(1772). Although published anonymously the text was likely prepared by Stieglitz. Hailstone (1792) copying Werner records that the collection was eventually sold to the Theresian College in Vienna.[1674] One can speculate that the Stieglitz' colored mineralogy *Spicilegivm Qvarvndam Rerum Natvralivm Svbterranearum Lipsiæ Collectarvm* (1769) was perhaps a prospectus to attempt to sell the collection to a Saxon Noble. However, when this failed to produce a buyer and Stieglitz died,

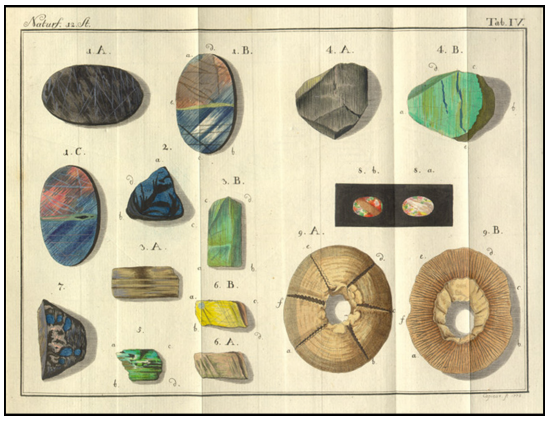
[1673] J.C. Freiesleben., "Sächsische Mineralien-Verzeichnisse. Beytrag zur sächsisch-museographischen Litteratur," *Magazin für die Oryktographie von Sachsen*, **1** (1828), 131-157. [Annotated catalog of mineral collection catalogs published in Saxony upto 1828.]

[1674] J. Hailstone., *A Plan of a Course of Lectures on Mineralogy*. Cambridge, 1792.

the full collection catalog was published to sell the cabinet.

### 15.3.99 Der Naturforscher

The periodical, *Der Naturforscher* (Halle, 1774-1804) edited by J.E.I. Walch distinguishes itself among the early science periodicals because it was one of the first to publish a significant number of original contributions, as opposed to duplicating or reprinting from other sources. It was also the first to limit itself to natural science. The title page vignette shows a gentleman receiving papers from cherubs who are depicted observing and collecting zoological and botanical specimens. The folding plate, a hand-colored engraving of minerals and gemstones, is a typical illustration in a late eighteenth century journal.



Walch, 1772

### 15.3.99 Ledermüller

One of Martin Frobenius Ledermüller's [1719-1769] rarest works, *Physikalisch-mikroskopische Abhandlung vom Asbest, Amiant, Stein* (1775) describes asbestos, and its examination under the microscope. Towards the middle of the 18th century microscopical observation became very fashionable and Ledermüller's publications enjoyed great popularity. He produced a number of splendid microscopical works, all beautifully illustrated of which *Mikroskopische Gemüths- und Augenergötzungen* is his best known. They were all published in Nuremberg, the flourishing center of fine natural history iconographies.



Ledermüller, 1775

### 15.3.99 Gmelin

Johann Friedrich Gmelin [1748-1804] was a member of the famous family of eighteenth century German scientists and naturalists. He was professor of medicine at the University of Tübingen and professor of philosophy and medicine at the University of Göttingen. In the spirit of his time, Gmelin worked in many fields including natural history, mineralogy, chemistry, entomology and botany.

In 1776 and 1777, Gmelin published his *Allgemeine Geschichte der Gifte* (General History of Poisons), which was published in three parts, the third of which describes those poisions found in the mineral kingdom. The other two parts describe those derived from animals and plants. Gmelin provides information on the history of the use of these poisons, their sources, and preparation. There is also a large amount of information relavent to the pharmaceutical use of the substances.

An extremely rare and widely unknown atlas of 60 hand-colored engraved plates is not mentioned in most bibliographies, but was in fact prepared to accompany this work. No copy of this atlas has been located to verify its mineralogical content, but with Gmelin's

interest in mineralogy it seems likely that there are some relavent illustrations.

### 15.3.99 Hamilton

William Hamilton [1730-1803] diplomat, archaeologist, and collector, and British envoy and plenipotentiary at Naples from 1764, where his embassy became a cultural and musical centre; he entertained many travellers on the Grand Tour, studied Vesuvius (recording his observations in Campi Phlegraei: Observations on the Volcanos of the Two Sicilies, 1776), collected so-called Etruscan vases and paintings, and in 1791 married, as his second wife, Emma Hart (born Amy Lyon) who was to achieve notoriety as the mistress of Nelson. The Hamiltons were recalled to England in 1800, where Sir William died, with both Emma and Nelson attending his deathbed. His friends and correspondents included Beckford and Horace Walpole, and his collections exerted a wide influence on neo-classicism in Britain; one of his most important collections of vases, terracottas, coins, etc., sold to the British Museum in 1771, laid the foundation for its department of classical antiquities.

Fourth son of Lord Archibald Hamilton. In 1758 he married Catherine Barlow, the daughter of Member of Parliament Hugh Barlow. He became ambassador of England in Naples in 1764. He studied the excavations at Pompei and published scientific books on vases. His first collection of vases he sold to the British Museum, the second collection went down with the ship that was transporting them to England on 12 Oct 1798.

After Catherine's death he married Emma Lyon when he was sixty years old. Emma eventually became far more famous than her husband as the mistress of Lord Nelson.

His *Campi Phlegraei. Observations on the Volcanos of the Two Sicilies* (1776) is a monumentally beautiful work, highly prized for its beautiful plates showing panoramas of Italian volcanoes, as well as minerals found around volcanoes. Text is in parallel columns of English and French.

Also on view are striking hand-colored etchings by Pietro Fabris that depict the



Hamilton, 1776

eruptions of Mount Vesuvius and the fiery fields of the Campi Phlegraei. In The Eruption of Mount Vesuvius on August 9, 1779, Fabris dramatically records the spectacular views that drew 18th-century travelers to the region to sketch and to collect rocks, shells, and antique fragments found on the path of the flowing lava.

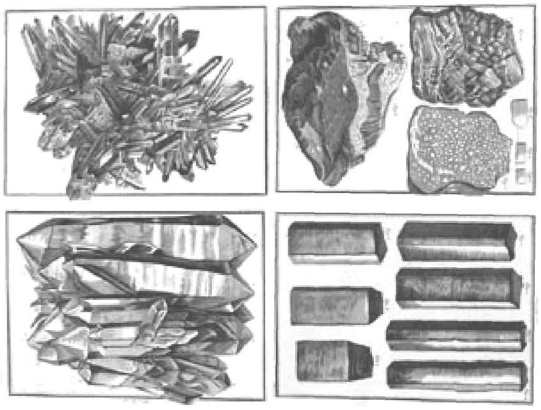
This huge tome describes volcanic areas around Pozzuoli to the west of Naples, Vesuvius, islands in the Bay and Mount Etna in Sicily. Campi Phlegraei was expensive to produce but provided clear, precise, more useful and much more detailed explanations of volcanic activity than had previously been published, and included Sir William Hamilton's own theories that volcanoes were creative rather than destructive forces. Published in both Italy and England it sold widely throughout Europe and was hailed as a masterpiece.

Sir William Hamilton, the diplomat and archaeologist, served as British envoy to the court of Naples from 1764-1800. It was at the end of his second year of residence in Naples that Vesuvius began a series of great volcanic eruptions, all of which he witnessed, in 1767, 1779 and 1794. He produced several treatises on earthquakes and volcanoes, including these observations on Vesuvius and Etna, published

in 1776. The text - the first major contribution on volcanology since the Renaissance - is Hamilton's own, while the fifty-four hand-coloured plates which describe the activity of the volcanoes are the work of Pietro Fabris. A spectacular night view of the eruption of Vesuvius on 11 May 1771 is shown here, the lava forming a beautiful cascade of fire; Hamilton is depicted drawing the original in the lower left corner. Knighted in 1772, Hamilton was a notable collector. He aided his friend, William Hunter, the original owner of this volume, in acquiring coins and medals from Italy. He was also the husband of Emma, Lady Hamilton, the mistress of Admiral Horatio Nelson.

Fabris was the sole distributor of the work, which was originally published at 60 Neapolitan ducats for Part I and Part II. Jenkins and Sloan state that 'some copies have bodycolour and gum arabic added to the etchings, perhaps indicating that they were de luxe versions'—(I. Jenkins and K. Sloan., *Vases and Volcanoes* (London, 1996), 'Catalogue' 43).

### 15.3.99 Guettard



Guettard, 1779 (Uncolored)

Jean Etienne Guettard [1715-1786] wrote a number of works on the geology and mineralogy of France. He is best known for his discovery of the volcanic nature of Auvergne and his attempt to consruct the first geological map of France. Guettard also worked to create a large series called *Description Générale et Particulière de la France*. Part of that series was an illustrated mineralogy that described the minerals of the region of Dauphiné. It has the title *Mémoires sur la minéralogie du Dauphiné* and is by far his most important mineralogical work. The first edition appeared in 1779, and according to some sources a special very limited edition appeared with the 19 plates to this work hand-colored. Unfortunately, no copy of this colored mineralogy has been examined. A second edition, with plain plates appeared in 1780 and was reprinted in the 1999.

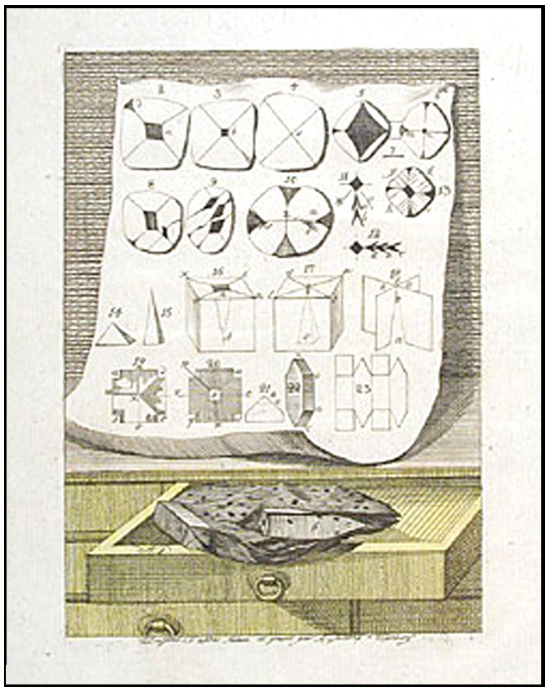
### 15.3.99 Heinitz

Friedrich Anton von Heinitz or Heynitz [1724-1802] was a member of an important aristocracy family in Saxony. He was one of the founders of the famous Freiberg Bergakademie, which produced most of the mining engineers of central Europe. Heinitz is considered as the reformer of the mining industry of Braunschweig, having reorganized the mining and metallurgical operations of Prussia. He wrote the *Entdeckung einer dem Kreuz-Steine* (1780) that describes the mineral called the "cross-stone," or Chiastolite (a variety of Andalusite), its occurance, and use. He includes a realistically hand-colored frontispiece that shows a parchment covered with drawings of various "cross-stones" resting on top of a wooden cabinet, holding a specimen of the cross stone.

### 15.3.99 Houttuyn

Martinus Houttuyn [1720-1798] studied medicine in Leyden, where he graduated in 1749. After graduation he went to Amsterdam, where he opened a medical practice. He probably was related to the publishing house of Houttuyn in Amsterdam, and through this connection was introduced to Jan Christiaan Sepp [1739-1811]. Their association caused Houttuyn to produce several important translations.

As a young man, Houttuyn decided to write an elaborate, well illustrated explanation of Linnæus' natural history method. Realizing that this project would take many years, he took the precaution of building up a large collection of natural history objects. From this collection, specimens were chosen for illustration to support various points discussed



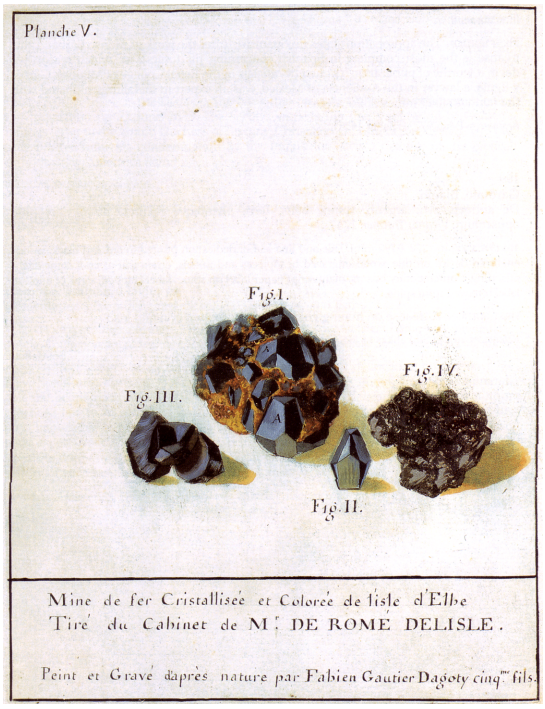
Heinitz, 1780

within the body of the work. Publication began in 1761 and was completed 37 tomes and over 22,000 pages later in 1785. The complete work consists of three main parts, namely: zoology (18 vols., 143 plates), botany (14 vols., 105 plates) and mineralogy (5 vols., 48 plates). It ostensibly is based upon the tenth edition of Linneaus' *Systema Naturæ*; however, it is more a compilation than a translation. Each volume is well illustrated with numerous copper plate engravings.

The mineralogical portion of the work, *Natuurlyke Historie ... Mineraalen*, published in five volumes between 1780 and 1785 is the concluding section to Houttuyn's work. It is called volume 3, parts 1-5, tomes 33 to 37. The plates to this work are beautifully executed renderings that show examples of fossils, corals, marbles, stalactites, gypsum, calcite, agates, jaspers, precious stones, and various metallic ores. As was typical of the time, either plain or colored versions could be purchased from the publisher.

### 15.3.99 Gautier d'Agoty

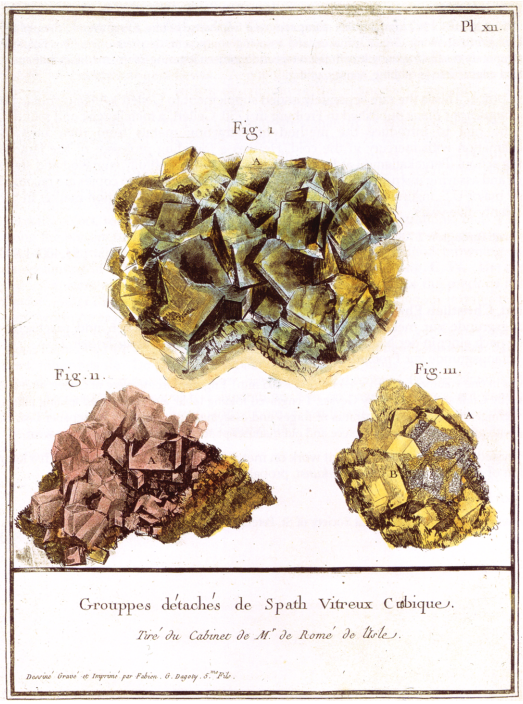
Fabien Gautier d'Agoty was the fifth son of Jacques Gautier d'Agoty [1716-1785], who was assistant and successor to the pioneer of mezzotint printing, Jacob Christoph Le Blon. Fabien D'Agoty died in Paris in 1781, having just started publication of his only book, *Histoire Naturelle ... Regne Mineral*. This work uses direct printing of tints, in a mezzotint technique, to create the mineral illustrations – the only time this technique was used in a mineral book. The process proves highly successful, making this title one of the finest colored mineralogy books ever published. Unfortunately very, very few copies of this book were ever printed, and even fewer subscriptions completed, making this also one of the rarest of all mineralogies, with only a few copies known to contain the full complement of plates.




Gautier D'Agoty, Prospectus (1777)

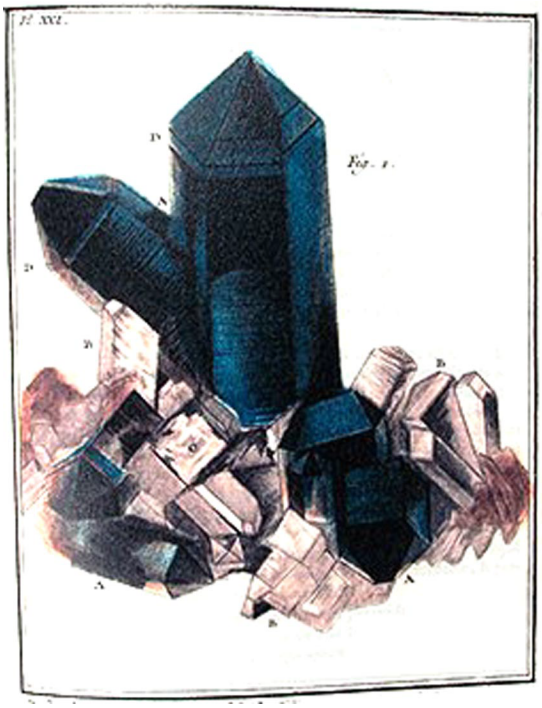
In 1776 D'Agoty secured a royal permission to publish a multi-volume treatise about the realms of nature that would include a collection of color-printed plates and explanatory text devoted to the three Kingdoms of Nature: animals, plants and minerals. Initially to test his technique and perhaps satisfy himself that the process would work, D'Agoty published in 1777 an extremely rare *Prospectus* containing

ten colored plates showing excellent renderings of crystallized mineral specimens. The style of the design of these plates would be repeated when the more robust *Histoire Naturelle* appeared four years later, but none of the illustrations used in the *Prospectus* were reused. To date, only two copies of the *Prospectus* have been located.




Gautier D'Agoty (1781)

Finally, in 1781, D'Agoty announced the recent publication of the *Histoire Naturelle ... Regne Mineral*. He indicates that this was only the first part of what would eventually be a complete illustrated series covering all aspects of natural history. He chose minerals as the subject for the first sections, and began accepting subscriptions for a volume that would be published in 8 to 10 parts or decades, containing 10 plates each. The first section appeared around May 1781 with the second following in June. However, after publishing the third decade, D'Agoty died suddenly suspending publication. Eventually, his widow resumed issuing sections, until a total of seventy plates were printed. For the written descriptions of the plates, D'Agoty had the good fortune of securing the great French crystallographer Jean-Baptiste Louis Rome de l'Isle. Each of the plates identifies the collection to which the figured specimen belongs. Included are a fine Fontainebleau sand calcite from the collection of Rome de l'Isle, an octahedral galena cluster from the collection of Abbe Nolin, and an Hungarian sphalerite from the cabinet of the mineral dealer Jacob Forster.



Gautier D'Agoty, 1781, Plate 21

### 15.3.99 Uibelaker

*System des Karlsbader Sinters unter Vorstellung schöner und seltener Stücke* describes and illustrates sections of stalactites and stalagmites (254 specimens in all) from the famous Karlsbad caverns of Germany. Until recently this book written in the eighteenth century was the standard work on its subject. According to the forward, Uibelaker selected these specimens from his collection of over 600 examples to best illustrate the varieties of color and form found within the caverns. They are illustrated in lively hand-colored renderings on the thirty-nine plates. Also included are two color wheels based on the schemes of Schiffermuller

and Newton. Gatterer says of this work that "it contains many new observations, mostly related to microscopic observations and vocabulary, but ... is confused with too many hypotheses. The plates are beautiful."




Uibelaker, 1781, Plate 29

One of the largest collections to Carlsbad Sprudelsteinen was in 18. Century in the material assets cabinet of the Benedikti nerklosters and realm pin Peter living with Konstanz. The green that and Gestalter of this material assets cabinet was Pater Franz Ue more belacker. He had to withdraw around 1783 due to his change into the school service bathing from the convention. He briefly before wrote an extensive publication over that Carlsbad Sprudelstein with the title "P. Franz Uibelakers Sys tem Carlsbad sinter" (fig. 11). 26 the magnificent work in the Folioformat 1781 in attaining appeared. These splendourful volume with 38 color charts with the designs Carlsbad gushing unities, at the same time evil field witnesses in the time of the clearing-up. from the collecting passion and looking for to realization by Pater of the Franz A contemporary appreciation of this work comes from no smaller one than Joseph Friedrich baron to Racknitz27: "it contains this work 254 quite industriously and well illu minierte copper of Carlsbader sinters. And there the author egg ne to course-add particularly in reputation of the emergence of these stones quite carefully prepared description has: like that the whole work is evenly so beautiful for the eye, as useful for rereading. over this it is too precious for many, by costing 12 to 14 Thlr. "2 "

From the preface come out out, that 600 copy of Karl bader sinter in the collection the cabinet vorhan the be be must. Beside raw pieces copies also ground are shown, wel che structures and designs very beautiful to the largest part show (Taf. 1 and 2). on the kolorierten boards Divide this collection, under it Spru of delstein pieces, lie today in prince mountain archives in Donaueschingen. It did not succeed in the apron of this exhibition to get an information over the presence of originals from the Ue belacker volume. The collection is to be visited not publicly accessible and for foreign scientists because of shortage of staff not.

Evil field remarks over those Carlsbad source paragraphs green itself on own observations and exchange of experience with the oft-quoted stone cutter the Joseph Mueller. In the syste matischen allocation evil field leans Johann Gottschalk Wallerius against the Swedish natural scientist. arranges 29 evil field its enumerating Carlsbad sinter into three sections: the ground connection (earth kinds), the kinds of stone or sinters, as well as the Pisolitharten or pea stones. In the fourth section the papers over that are enumerated Carlsbad sinter under at derem from Wallerius, bridging man, Ludwig and Cronstedt with the descriptions and interpretations to the emergence of these source paragraphs.

### 15.3.99 Wünsch

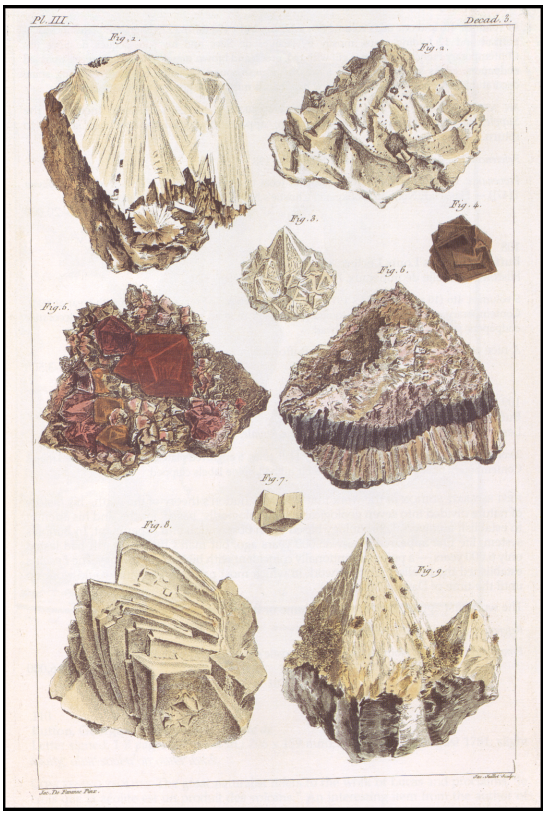
The *Briefwechsel über die Naturprodukte* was published anonymously but is attributed to Christian Ernst Wünsch [1744-1828]. The first volume of a proposed series describes minerals, fossils, agates, and gems in a series of letters covering the entire spectrum of mineralogical knowledge. Included are discussions of the ores and minerals of the various elements such as silica, magnesia, calcic, etc., as well as fuels, ores, gemstones, metallurgy, smelting, mining and fossils, etc. The color illustrations scattered throughout the volume delightfully illustrate in crude, colorful renderings various mineral specimens, a panorama of the famous Schneckenstein topaz locality in Saxony, various gemstones, and the interior of caves. It is not clear if other volumes other than the rare mineralogical volume ever appeared.



Wünsch, 1781

### 15.3.99 Buc'hoz

Pierre Joseph Buc'hoz was born at Metz, France on January 27, 1731. A great French naturalist and botanist, he became in 1759 physician-ordinary to Stanislaus, King of Poland. Buc'hoz needed more stimulation, however, and thus his restless energies were soon applied to the publication of books about natural history. The best known of these, published in 1772, has the title: Histoire universalle du Regne vegetal, and comprises 25 volumes with 1,200 plates. Among his other three hundred published works were several concerning mineralogy. After a long and productive life, Buc'hoz died at Paris, France on January 30, 1807.



Buc'hoz, 1782

Buc'hoz' great addition to colored mineralogical literature was his 1782 *Le Dons Merveilleux et Diversement Colories de la Nature dans le Regne Mineral*, which was published as the third part of a general treatise on natural history comprising plants, animals and minerals. It is exquisitely illustrated with many hundreds of hand colored figures displayed on its one hundred plates. Everything concerning geology, paleontology and minerals is pictured, including many fine minerals and crystals. The seven pages of text accompanying the work describe the figures on the plates. Some of the illustrations are copied from other works but the majority are original. Unreserved praise should be given to the numerous artists and engraves who designed the plates to the author's specifications. This work was also sold with uncolored plates, presumably as a cheaper version of the book.

Pierre Joseph Buc'hoz was born in Metz, France in 1731, the son of a middle-class attorney. He was at first persuaded to follow

his father's profession, and embarked on a career in law, passing the bar at Pont-à-Moussen in 1750. However, he did not find that profession agreeable, and after some time he moved to Nancy where he took up the study of medicine, a field more closely related to his passion for natural history. He graduated with his medical degree in 1763 and received a prestigious appointment as physician to King Stanislaus of Poland. He was accused of not fulfilling his duties, however, and quit to devote his energies to the study of botany, medicine, economics and mineralogy, eventually publishing over 300 volumes on these subjects. His works include a mineralogy of France, and Wallerius Lotharingiae (1769), a review of the minerals, rocks and fossils of his native Lorraine, organized more or less according to the system of Wallerius. He was also an artist, and many of the botanical illustrations in his books were derived from his own sketches. Unfortunately his writing and research were hastily assembled, prone to errors and free of any real contributions to scientific knowledge. Nevertheless he produced some of the few color-plate mineralogical works of the 18th century.

Pierre Buc'hoz' most important works in mineralogy were his *Planches Enluminées les Animaux, le Vegetaux et les Minéraux*, issued in parts from 1776 to 1781 (reissued with new title pages in 1778-1782), and *Les Dons Merveilleux dans le Règne Minéraux*, issued from 1782 to 1797. The two works have 60 plates in common (reproduced here from a very rare copy in the Mineralogical Record Library), and 40 new plates were added to the second series for a total of 100. Unreserved praise must go to the numerous artists and engravers who produced Buc'hoz' plates, foremost among them being Jean Baptiste Desmoulins (b. 1740), as well as Jean Charles Baquoy (1721-1777), Jean Victor Dupin (b. 1718), Claude Mathieu Fessard (1740-¿1803), Jacques Juillet and Jacques de Favanne. After Buc'hoz had lost his wife and suffered the calamities of the French Revolution, he was taken in by a woman who had worked for him for 25 years as a colorist. He died in poverty in Paris in 1807.



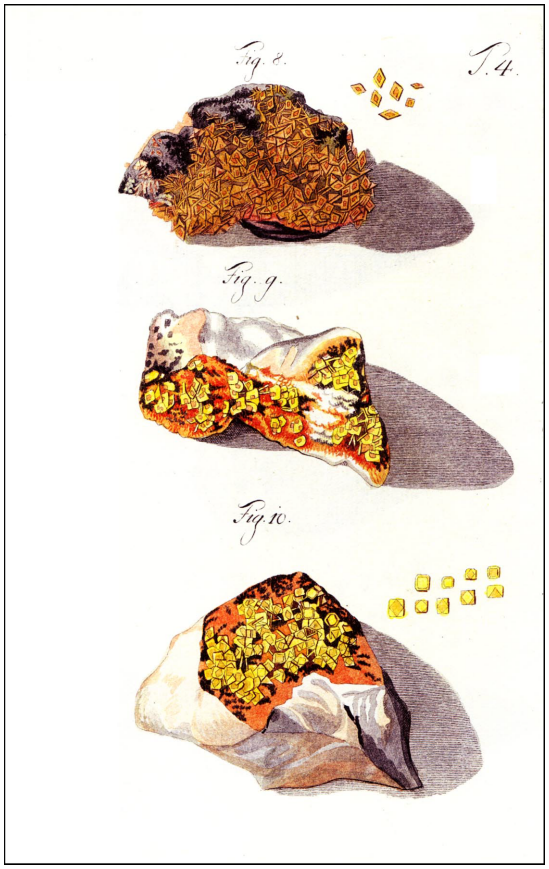
Buc'hoz, 1782 (Plate 3)

Reference: Wilson, W. E., and Schuh, C. (2001) Introduction to the new edition, with biographical notes on the author and his works, in Buc'hoz, P. J., The Marvellous Gifts of Nature, diversely colored, in the Mineral Kingdom (1782). New edition published by the Mineralogical Record, Tucson, pages 5-11.

### 15.3.99 Wulfen

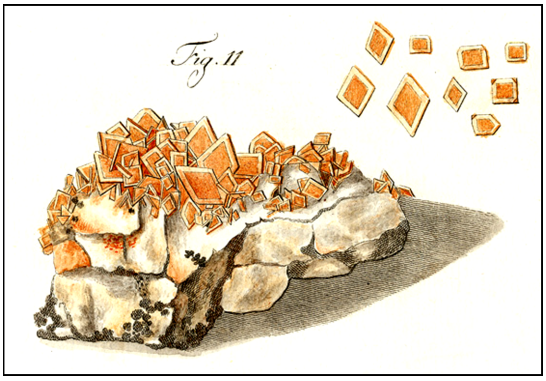
Franz Xaiver von Wulfen was born at Belgrad, Serbia on the 5th of November, 1728. His father was a field marshal with noble ancestry in the Austrian army. Wulfen, himself, chose to enter as a novice the Order of the Society of Jesus in Vienna when he was seventeen. There he showed a marked talent in philosophy and mathematics, and thus was allowed to expand his education in these areas. After teaching appointments at several schools throughout the Austro-Hungarian empire, Wulfen eventually was transferred to Klagenfurt, the capital of Carinthia, Austria, where he took up the professorship of natural

philosophy and mathematics, a post he held for much of his adult life. He died at Klagenfurt on March 17, 1805.




Wulfen, 1785, Plate 4

The dramatic beauty of Austria is undoubtedly what first lured Wulfen into long natural history hikes. Before coming to Klagenfurt, he was already an established botanist, having published several important papers. It was only normal that he continued his wanderings to observe plants and animals. During these treks through the Carinthian mountains, Wulfen encountered some of the numerous lead mines then active, and this is how Wulfen was introduced to the secondary minerals associated with lead ores. The local miners descriptively called one of the minerals "gelbbleierz" [yellow lead ore], and its beautifully formed crystals certainly intrigued Wulfen because he began to regularly visit the mines to obtain more specimens. In time, this lead to the publication of Wulfen's great mineralogical book, *Abhandlung vom kärnthnerischen Bleyspate* published at Vienna in 1785. Of course in 1845, William Haidinger wrote the recognized scientific description for "gelbbleierz" renaming it wulfenite in honor of its first investigator, but Wulfen's monograph on the mineral is much more than a beautiful illustrated mineralogy. In this book the author shows off his great mineralogical skill. He is not confined to simple descriptions of wulfenite, he is also among the first to write about mineral paragenesis – the sequential order in which one mineral is deposited after another. Wulfen also assigns exact localities and distinguishes specimens from other localities in Carinthia by means of physical characters like color, lustre, and associated minerals. The text is complemented by twenty-one finely engraved, hand colored plates, showing mostly specimens of Austrian wulfenite. For their realism, these mineralogical illustrations are among the finest ever created.

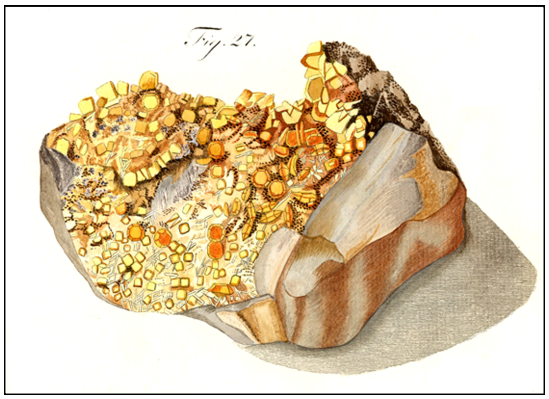



Wulfen, 1785, Fig. 11

### 15.3.99 Klaproth

The famous German chemist Martin Heinrich Klaproth published numerous papers on the chemical analysis of a large variety of minerals. One paper on the tin ores of England was translated in 1787 by John Gottlieb Groschke as *Observations Relative to the Mineralogical History of Cornwall.*[1675] The text deals with the chemical analysis of tin and

[1675] Original article, M.H. Klaproth., *Schriftteller der Gesellschaft für Naturforscher in Berlin*, **7**, (1786).




Wulfen, 1785, Fig. 27

copper ores from Cornwall in England. It is based on research done in cooperation with the English geologist, John Hawkins, who supplied samples of the ores. Using these specimens, Klaproth preformed many chemical experiments, and the descriptions of his tests together with their results makeup the content of the book. The thoroughness of the study was considered important enough to have this English translation prepared. It is accompanied by a hand-colored frontispiece that illustrates various specimens of the wood tin (cassiterite).

### 15.3.99 Karsten

The noted German mineralogist, Dietrich Ludwig Gustav Karsten [1768-1810] published a descriptive catalog of the mineralogical portion of Nathanael Gottfried Leske's natural history collection, *Des Herrn N.G. Leske hinterlassenes Mineralienkabinett* (1789). Since its publication this work has also been known by the name *Museum Leskeanum*.

Leske was one of the most prominent student's of Abraham Gottlob Werner. Between 1782 and 1787 it was under the supervision of Werner that Leske arranged his large mineralogical collection according to Werner's theory of mineral collections. Upon Leske's death and at the urging of his heirs, Karsten another supporter of Werner continued to enlarge the collection and wrote this descriptive catalog. It was an important publication for presenting a practical example of Wernerian doctrine, thus helping to cement the theory in geological science. This publication also helped secure the sale of the 7,331 specimen collection to the Dublin Natural History Museum in 1792 for handsome sum of 1,350 pounds.

The extremely rare second volume of Karsten's work, contains at the end five hand-colored plates of minerals that were described in the nineteenth century as extremely beautiful productions. Unfortunately, no copy of this volume has been examined to make a first hand confirm of this.

### 15.3.99 Spalowsky

A physician of the "Bürger-Regiment" in Vienna, Joachim Johann Nepomuk Anton Spalowsky [1752-1797] had an intense interest in natural history. He published the rare *Vorbothe der Naturgeschichte* in 1789 that was a "prodromous" or prospectus for a proposed series of natural history volumes. It contains 25 magnificent hand-colored plates that show vivid coloring heightened with gold to show off the depictions. These plates comprise 8 of mammals, 4 of birds, 3 of insects, 2 of fish, 4 of flowers, and 4 of minerals (gold, silver, copper fluorite, and malachite). The magnificently colored frontispiece shows a variety of animals, birds, and plants within a landscape. Unfortunately, this extremely rare prospectus is all that appeared. Apparently another state of the plates exist, these being uncolored.

### 15.3.99 Bertuch

A very successful publisher Friedrich Justin Bertuch [1747-1822] was the son of a physician, who became an orphan at an early age. After studying first theology and then law in Jena, he later entered publishing in Weimar, Germany, eventually becoming the largest employer in the town. As a successful businessman Bertuch realized that you need well educated workers to manufacture high quality goods. In the past education always was the monopoly of the church and the rich minority. In 1794 Prussia passed a law that made schooling compulsory for all 6-14 year old children. At the time specially prepared textbooks for children were rare. That's why Bertuch planned his large workpiece of the *Bilderbuch für Kinder* very carefully. He had a vision for producing a picture book for children that would show the pictures from the entire

world. It was published in 12 volumes between 1790 and 1810 with 1,187 prints of a wonderful and eclectic nature. It was prepared based on eight main features:

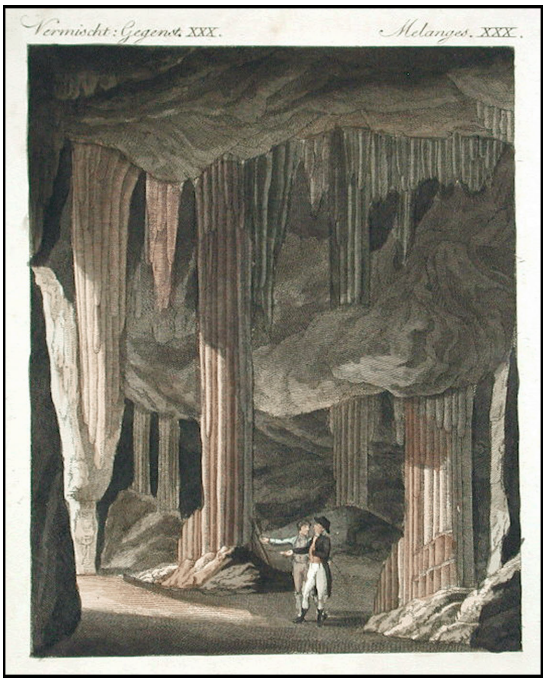
1. The image quality has to be very high. Every image must be as real as possible.
2. Plate must not be overcrowded and disturbing.
3. Shown things must not be printed too small. If there are different things on one plate proportions between them must be right.
4. Text has to be written easy and entreating for the kid.
5. The plates shall show things which are alien, rare and educating, not common.
6. The books must be affordable to parents with midrange income.
7. The whole workpiece must not be published in one large book but in parts.
8. The plates of the books must have a systematical arrangement.



Bertuch, 1800 (Plate 125)

The *Bilderbuch für Kinder* was published in both colored and plain editions, but the reverse sides of the plates were always kept empty so that children could cut single images out of these books and hang them on the wall or fill the plain prints with their own colors. Like Sowerby's books, Bertuch's work appeared over the years in 237 sections, which in all contained 1,187 plates, and almost 15,000 pages. The text is divided into sixteen broad topics: mammals, birds, fish, insects, plants, humans and their cloth, worms, shells, corals, amphibians, minerals, architecture, antiquity, mixed, roses and fruits.

There is undoubtedly some mineralogy illustrated in this work, but alas no copy of the book has yet been seen to examine fully and determine its mineral content. However, the plates on other subjects that have been seen show them to be exquisite illustrations. So there is some hope the mineral plates are good quality.



Bertuch, 1798 (Plate 30)

### 15.3.99 Baumeister

Joseph Edlem von Baumeister was an Austrian historian, author and publisher. Educated at the University of Vienna, he received a degree in 1770. In 1788 he began the six-volume publishing effort, *Die Welt in Bildern* (The World in Pictures), that was aimed at young students. Volumes covered the three natural kingdoms, as well as the occupations of men. In 1791, the fourth volume of the series appeared. It was devoted to "Das Mineralreich" (The Mineral Kingdom). The series concluded in 1792, and the reigning monarch Kaiser Franz II was so impressed that he hired Baumeister to oversee the education of his sons, the Princes

Ludwig and Rudolf. This was a tremenous honor that Baumeister apparently carried out to the Kaiser's satisfaction because he was subsequently awarded a position as Special Advisor to the government.

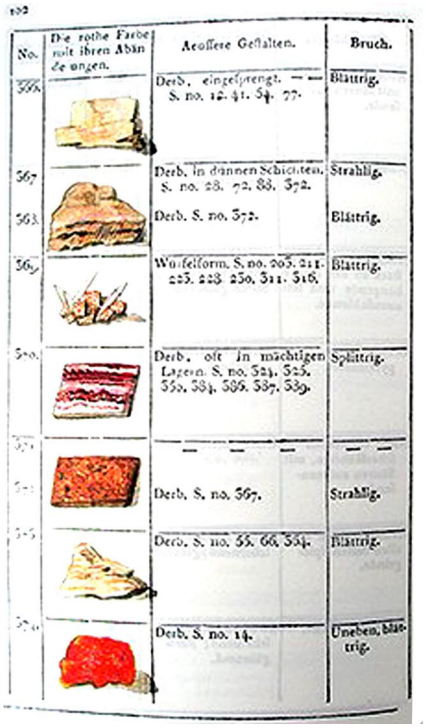


Baumeister, 1791 (Plate 1)

Baumeister's *Das Mineralreich* is illustrated by copper engravings made after actual mineral specimens from an unspecified, but good quality collection. The initial paintings were the effor of Johann Sollerer [1747-1809], a Viennese painter of miniatures. Engravings of the paintings were then executed by the Mansfield family of Viennese engravers, including Johann Georg Mansfield [1764-1817], Johann Mansfield [1720-1825] and Johann Ernest Mansfield [1739-1796]. Like many of the juvenile literature of the period, copies of the book could be acquired with the 23 plates showing 105 mineral specimens either plain or colored.

### 15.3.99 Lenz[1676]

[1676] W.E. Wilson., "Johann Georg Lenz and his Mustertafeln (1794)," *Mineralogical Record*, **27** (1996), no. 3, p. 191-195.



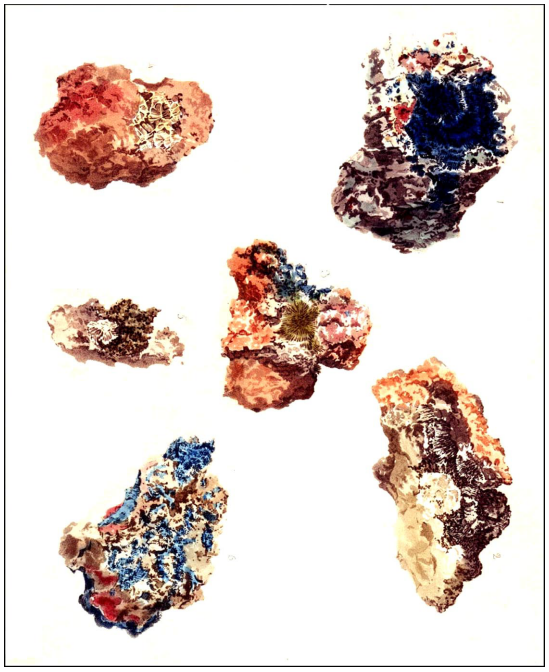

Lenz, 1794 (Page 100)

The *Mustertafeln der bis jetzt bekannten einfachen Mineralien* (1794) of Johann Georg Lenz [1748-1832] is based on Wernerian principals. It uses the physical qualities of minerals to create an elaborate, early field guide to mineral determination. In the forward, Lenz states that these "Mustertafeln" or specimen tables are intended to help friends of mineralogy become acquainted with the simple minerals. This book is admirable for that purpose as it consists of tables divided into color, external form, break or facture, transparency and lusture, hardness and finally the name of the mineral. Unique to this work are the four hundred water color drawings of minerals that are placed in the color column. These figures, each about one by one inch, are all rendered with quality and exactness as they were modeled from specimens contained in Carl August's mineral collection. This volume is undoubtedly one of the rarest colored mineralogies. In the forward, Lenz laments that due to the high cost of production, only as many examples will be published as there are subscribers. This list is included in the volume and includes the names

of Goethe, von Trebra, and Bertuch. But based on Lenz's statement, one can assume that the 26 copies purchased by the subscribers are all that were ever produced.

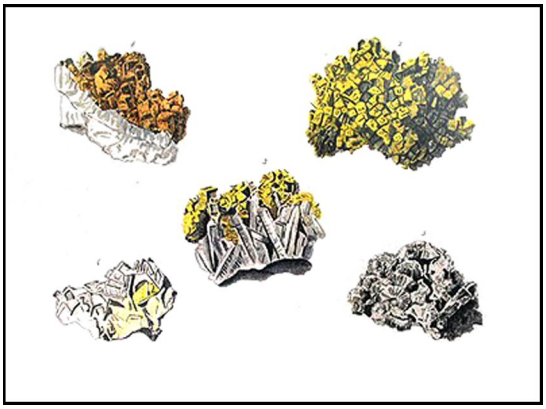
### 15.3.99 Rashleigh

Philip Rashleigh was born December 28, 1729 at London, England, into a privileged life of eighteenth century English society. After attending private schools, he completed his education at New College, Oxford, and then retired to oversee his considerable lands in Cornwall. From 1765 to 1801 he represented Fowey in the House of Commons. Rashleigh died June 26, 1811 at Menabilly, Cornwall, England.



Rashleigh, 1797

Rashleigh's secure life allowed for enthusiastic following of his chosen vocation, mineral collecting. Few collectors have ever had the opportunity and money Rashleigh had to collect minerals. During his lifetime the mines of Cornwall were producing fantastic specimens of cassiterite, chalcophyllite, olivenite, liroconite, cornwallite and cerussite to name but a few. Many of the finest crystallized specimens found their way into Rashleigh's mineral collection, making it one of the premier mineral cabinets of its time. Unrivaled as it was, the collection caused many mineralogists and curiosity seekers to make the excursion to Cornwall to examine it. Possibly, the complaints from his guests about the remoteness of the collection are what caused Rashleigh to publish *Specimens of British Mineral selected from the cabinet of Philip Rashleigh.* This sumptuous publication, issued in two parts, 1797 and 1802, contains a total of 54 engraved hand colored plates, showing many fine specimens from the collection. The excellent illustrations of the first part are attributed to the Cornishman Henry Bone, while the engraver Thomas Medland and the colorist Richard Underwood completed the rather rare second portion. Rashleigh's book is a remarkable example of eighteenth century hand coloring, yet it would be overshadowed within a few years by the works of another Englishman, Sowerby.



Rashleigh, 1797

### 15.3.99 Patrin

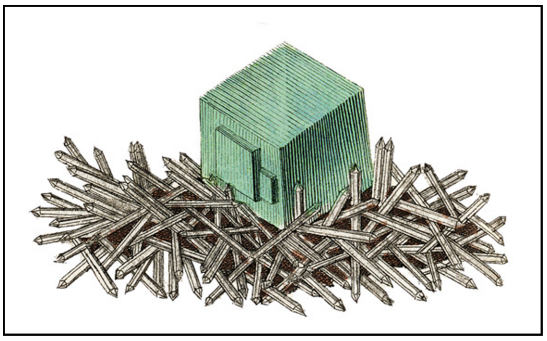
The French geologist and mineralogist Eugène Melchior Louis Patrin [1742-1815] studied chemistry and physics in France, after which he took a decade long mineralogical survey throughout Germany, Hungary, Poland, Russia and Siberia. His extensive travels in the Urals, Altai and other regions of Siberia lasted from 1780 to 1787. The mineral specimens he collected were sent back to St. Petersburg ahead of his return, but were partially confiscated P.S. Pallas, who took the choicest pieces for his own cabinet. The other Siberian specimens were offered for sale to

the Jardin du Roi Collection in Paris, on the stipulation that the group not be broken up. Patrin was engaged to prepare an updated version of the mineralogical section of Buffon's *Histoire Naturelle* which was published in 1801. This was an unusual version of Buffon's mineralogy because it is one of the very few editions that was illustrated with pictures of minerals, even though there are many editions of the work that contain very fine illustrations of the plants and animals.



Aquamarine and Smoky Quartz (Patrin, 1801)

The Parisian artist and engraver Jacques-Eustache Deseve, who specialized in natural history objects, designed the plates. He had previously worked with Buffon on plates that illustrated plants and animals published in the previous editions of his *Histoire Naturelle*. Then with the help of other Paris artists and engravers such as P. Jourdan, Jean-Gabriel Caquet [1749-1802], J.-A. Pierron [c1760-c1820] and Gérard-René Le Villain [1740-c1810] the plates to the work were created. The book was then prepared with the plates either plain or realistically hand-colored. It was later translated into Italian as *Storia Naturale dei Minerali* using the same plates.

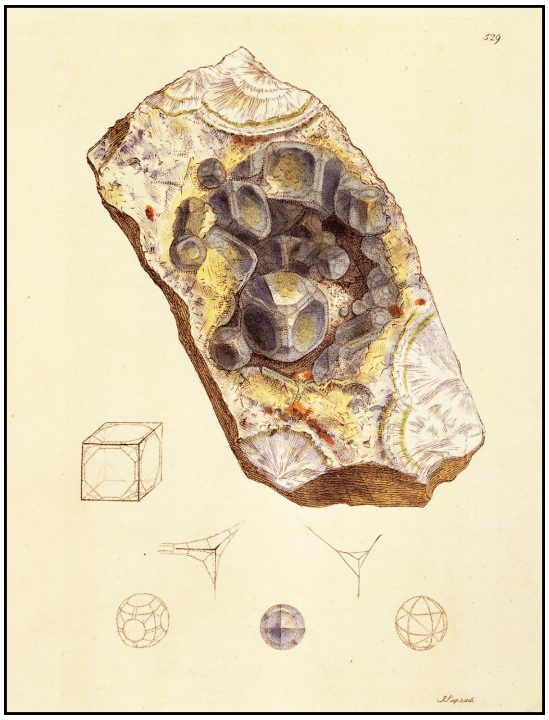


Fluorite and Quartz (Patrin, 1801)

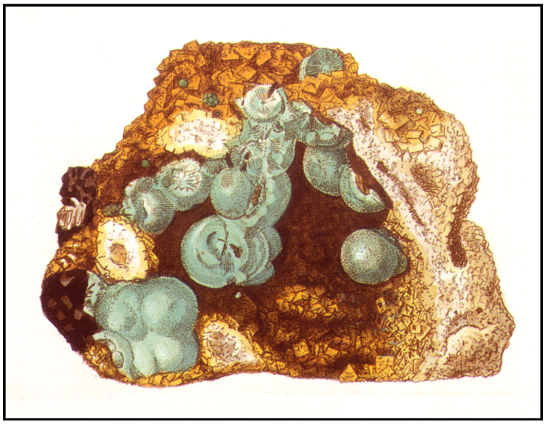
### 15.3.99 Sowerby

James Sowerby was born March 21, 1757 at London, England. He became a pupil at the Royal Academy, and was for a time one of their instructors. Around this period, Sowerby became interested in botany, and began to pursue the subject in his paintings. This brought the attention of botanists, who subsequently commissioned Sowerby to produce plates for their publications. The good reception of these illustrations lead in 1790 to the publication of his best known work, English Botany, which was finished in 1814 after thirty-six volumes, containing 2592 hand colored plates. He published many other colored and uncolored natural history works during his lifetime, these dealing principally with English fungi, zoology, mineralogy and conchology. Sowerby died at his residence in Lambeth, England on October 25, 1822.

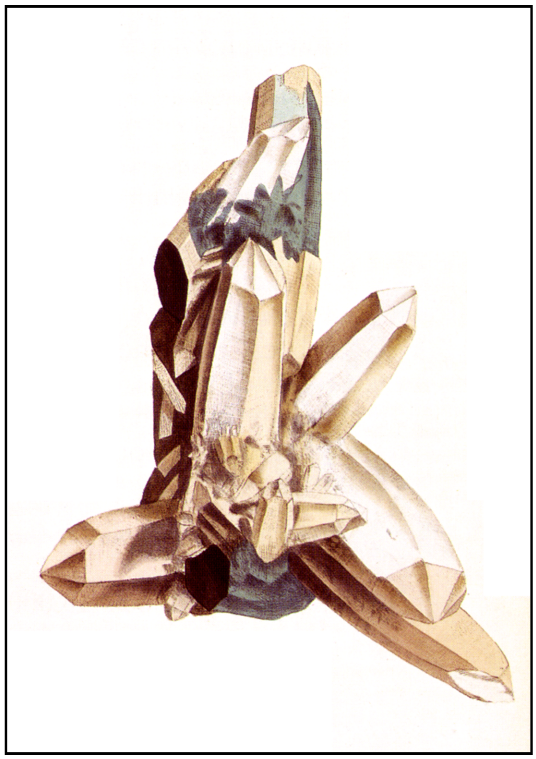
James Sowerby published two major mineralogic works along with several other minor ones. The first of these, started in 1804, has the title, *British Mineralogy: or, Coloured Figures intended to elucidate the Mineralogy of Great Britain* and should be considered one of the classic illustrated mineralogies. It is most noted for its 550 engraved hand colored plates that show minerals representative of the large variety found in Great Britain. When these volumes were published, Britain was the supreme world power, and there appears to have been great interest in the mineral wealth



Flourite (Sowerby, British, 1804, plate 529)



Malachite (Sowerby, British, 1804)



Quartz (Sowerby, British, 1804)

of the home nation. This is fortunate because also at this time many of the famous mines of Cornwall and Cumberland were still producing specimens from the oxide zone. Many notable mineral specimens, including several unsurpassed examples of some species, were discovered and preserved in this age. Sowerby sought out these unusually fine specimens and together with more typical examples, described and illustrated them in British Mineralogy, thereby creating an illustrated topographical encyclopedia of Great Britain's minerals that has not been eclipsed.

Although the execution of the illustrations is superior to many other illustrated mineralogies, the quality of the specimens used for the plates varies considerably. Consequently, one is struck with the number of unattractive plates contained in the volumes. Careful examination reveals however, that all of the plates are executed with precision because the intended purpose of the volumes was to accurately show examples of every type of mineral. Sowerby chose, therefore, to illustrate even mundane specimens if it would increase the completeness of describing the minerals of Great Britain.

Contrasting to this philosophy is Sowerby's other great illustrated mineralogy, *Exotic Mineralogy: or, coloured figures of such foreign minerals, as are not likely to be found in Great Britain.* Like its counterpart, this work too is noted for its 168 finely engraved hand colored plates of minerals. These plates though give an overall more attractive



Crocoite (Sowerby, Exotic, 1811)



Apatite (Sowerby, Exotic, 1811)

appearance than those of the British. In preparing Exotic Mineralogy, Sowerby sought for his illustrations only the best examples of minerals not then known in Great Britain. Weighted by the higher quality of model, the plates show more beauty than those found in the British, which illustrated many unattractive specimens. Unfortunately for the collector of such books, the Exotic, which is supposed to supplement the British, apparently had very few subscribers. The result being Exotic Mineralogy is one of the rarest of all mineralogical works, which is a pity as it contends with D'Agoty's book has the best colored mineralogy.

### 15.3.99 Egypt

Napoléon Bonapart conquered Egypt in 1798, and the antiquities of the land fascinated the French. A large scientific expedition was convened to study all aspects of the country. The published result of these studies was the *Description De L'Égypte, Ou Recueil Des Observations Et Des Recherches* published between 1809 and 1830. It is the first comprehensive description of ancient and modern Egypt, and the outstanding achievement of the savants who accompanied Napoleon's expedition to Egypt (1798-1801). The work is the greatest of a number of outstanding scientific publications by the French government detailing the results of exploration, unequalled by any other nation during the same period. The work now represents one of the only tangible results of Napoleon's planned occupation of Egypt. The only flaw in Napoleon's preparations for the invasion was a miscalculation of the Turkish reaction to France's unsolicited 'help' in sorting out its mostly unruly vassals, the Mamluks of Egypt. Had it not been for this, Napoleon's plan for following up military conquest by revolutionizing the economy and institutions of Egypt might well have created a modern European-style state, controlled by France, at the axis of all trade between Europe, India and the East. Plans to this end involved dispatching nearly 500 civilians to Egypt, the cream of whom were about 150 men drawn from

the Institut de France, and known popularly as the 'savants'.



Copper Minerals (Description de Egypt, 1809)

On arrival their first task was to make a thorough survey of every aspect of the country to assist with the planning of its future shape, and this was extended to cover the antiquities. The work was coordinate by the 'l'Institut de l'Egypte', founded in the appropriated house of Hassan Kachef (illustrated in the plates to the 'Etat moderne'), with Gaspar Monge as president. As early as October 1798 Fourier was entrusted with the task of uniting the reports of the various disciplines with a view to publication. Following the capitulation of the army to Egypt under General Menou (a convert to Islam), the savants returned to France where a commission was set up for the editing and supervision of the work. The huge volume of information to be published meant adopting an apparently haphazard modus operandi: when sufficient plates or text on a particular subject were ready they were published. Despite this publication of the entire work took over 20 years. Started under Napoleon's regime in 1809, there was a hiatus from 1813 until 1817 when the new Bourbon king, realizing the importance of the work placed it above politics giving his support to the plan to complete the publication. This was finally achieved in 1830.

Among the topics studied by the French were the natural history of Egypt, including the land's plants, animals, and minerals. The plates created to illustrate these subjects are amazing in their quality, being full and accurate representations of their subjects. Mineralogy is treated in the very last volume, perhaps in anticipation of better specimens being located. If only there were any good quality minerals specimens to have illustrated, this work would have been the finest hand-colored mineralogy ever produced. But the specimens are little more than low quality ore samples, that even so, are represented in their hand-colored renderings with almost photographic quality.

### 15.3.99 Mawe

Mawe, *Travels* Italian edition. A popular account of the geography, people and geology of Brazil. At the request of the Portuguese sovereign, Mawe made a two year expedition into the Portuguese territory of Brazil. This is the first account, in English, of the mineral wealth of the region. The plates scattered throughout the volume picture diamonds and gold being mined, a map of Mawe's travels, and machinery for mining diamonds, crystal drawings of diamond, topaz and tourmaline, minerals collected by the author, and various snail shells.

### 15.3.99 Stephenson

John Stephenson wrote *Medical Zoology, and Mineralogy* (1832) which contains colored plates showing the poisionous minerals. A relatively unknown colored mineralogy with somewhat crude though recognizable mineral depictions of many species. The text describes and illustrates various animals and minerals recognized in the medical science of the nineteenth century. Included are descriptions of many vemonous creatures and minerals from which medical preparations were derived. It was writen as a companion to the author's



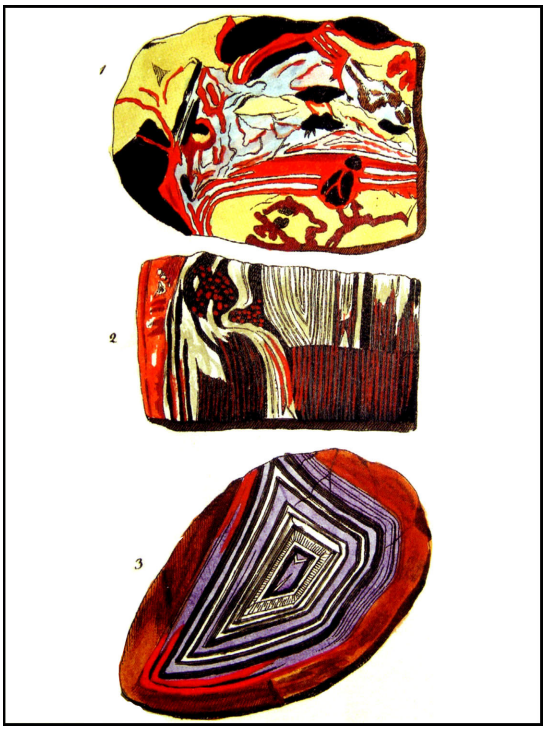

Mawe, 1812

previous work describing medical botany. The illustrations that accompany the text appear to be original and not copied from some other work.

### 15.3.99 Wilhelm

Gottlieb Tobais Wilhelm was a publisher who was disposed to natural history studies. His grand work in fact was a multi-volume set that in essence was an encyclopedia to all knowledge concerning plants, animals, and minerals. All of these volumes contained hand colored plates, and it is to Wilhelm's mineralogy that our attention is drawn.

Education is the driving force in the publication of many scientific books, likewise it is the cause for the appearance of many mineralogical volumes. Wilhelm's two volume *Unterhaltungen aus der Naturgeschichte. Des Mineralreichs* is an example of a work intended to be an encyclopedia of the science of mineralogy. The text of the volumes is based on the theories of Abraham Gottlob Werner, one of the greatest mineralogists of all time. Werner




Wilhelm, 1834

is in fact commemorated in the frontispiece of the first volume. However, the 132 mostly hand colored plates are the notable contribution of the work. Every aspect of mineralogy is illustrated in the plates. From a monocle'd collector examining a mineral cabinet, to a collecting picnic in rather formal dress, to the scenic views of various geological phenomena, to individual mineral specimens, everything related to the science is pictured. The quality of the illustrations is somewhat cartoonish however.

### 15.3.99 Schriften

*Schriften der in St. Petersburg gestifteten Russisch Kaiserlichen Gesellschaft für die gesammte Mineralogie* in two volumes was published in 1842. It was edited by Heinrich August Georg von Pott and Franz von Leuchtenberg. Being the chief publication of the St. Petersburg Mineralogical Society, volume one gives a detailed account of the society's activities from its founding in 1817 to 1842, particularly of its collecting and analyzing minerals. This part is illustrated with 8 lithographed plates, 6 of which show



Emerald (Schriften, 1842)

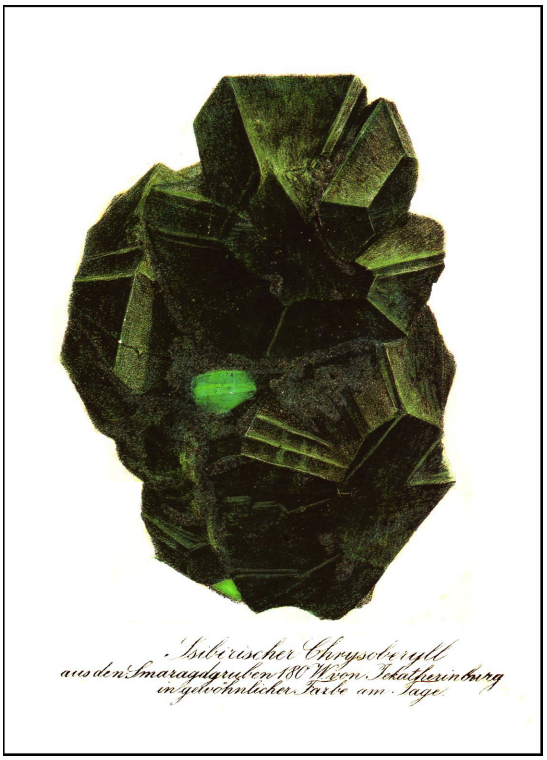
Siberian (and a Colombian) emeralds as well as Chrysoberyll (Alexandrite) in highly finished colouring, 5 of them enhanced with real sprinklings of hematite glitter. The second volume contains 20 selected reports written by members of the society. It is highly unusual to find good quality hand-colored illustrations of mineral specimens in journals, and these representatives are perhaps the best of that type.

### 15.3.99 Oken

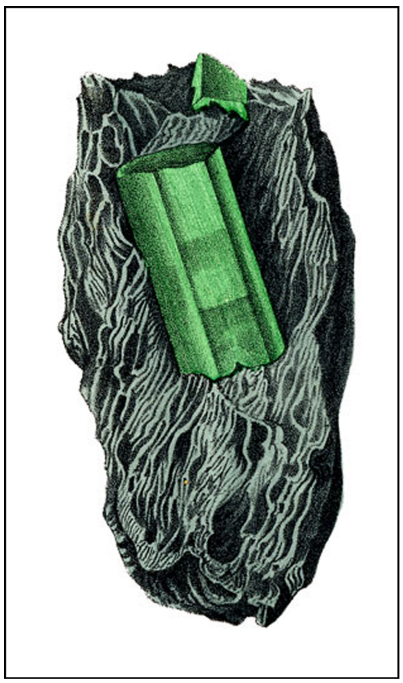
Lorenz Oken's *Allgemeine Naturgeschichte für alle Stände* (Stuttgart, 1833-1843) had an atlas published in 1843 with a total of 73 plates illustrating all types of natural history specimens. Included are six mineralogical plates of which two were hand-colored. Unfortunately, all of these plates are geological in nature and show principally cross-sections.

### 15.3.99 Schmidt

Schmidt is a elusive personality about whom surprising little is known. His full name was Friedrich Wilhelm Christian Schmidt [1799-1863], but wrote under the pen name of "F.A. Schmidt." According to Schenkenberg




Alexanderite (Schriften, 1842)



Emerald (Schmidt, 1850)

(1842), he had a medical practice in Metzingen (Messingen) in Württemberg. He is also

listed later by Gistel (1856) as a physician and a "Petrefaktenkenner" or someone knowledgeable about fossils in Metzingen. Schmidt was a member of the Society of Naturalists in Württemberg (Vereins für vaterländische Naturkunde in Württemberg). Besides his book on fossils *Die wichtigsten Fundorte der Petrefakten Württembergs* (Stuttgart, 1838), he authored an colored mineralogy.



Haüyne (Schmidt, 1850)

Schmidt's mineral book, which appeared in two editions, is an example of a very fine colored mineralogy. Titled, *Mineralienbuch, oder allgemeine und besondere Beschreibung der Mineralien* (Mineral Book, or General and Special Description of Minerals), this quarto sized volume first appeared in 1850 as an attempt to describe all aspects of mineralogy in a "coffee table" type book. For this reason, it was published with 44 hand colored plates of minerals. The plates are unsigned, so the artist and lithographer are unknown, but Schmidt does thank the mineralogist Friedrich Quenstedt [1809-1889] in Tübingen and the mineral dealer Adam August Krantz [1808-1972] in Berlin for their assistance. In the introduction to the volume, the physical characteristics of minerals, including form, hardness, specific gravity, and color are described. This is followed by rather standard descriptions of various species of minerals, some of which are illustrated by figures on the plates. Included among these are topaz, quartz, agates, beryl, and emerald. A second edition appeared in 1855.



Schmidt, 1850

### 15.3.99 Sowerby

Henry Sowerby was born March 28, 1825. He was a grandson of James Sowerby through George Brettingham Sowerby. He went to Australia in 1854, becoming a draughsman and eventually a drawing instructor. His attention turned to gold mining which occupied the last twenty years of his life. He died on September 15, 1891. Only one contribution to literature was authored by Henry, and it is of interest to mineralogy.

Henry Sowerby continued the tradition of his famous family when he published *Popular Mineralogy* for the general public. This is the first mineralogy to ever use chromolithography as a coloring technique. The text describes a mineral collecting trip to Cumberland, gives ideas about forming collections and the characters of minerals. A description of the minerals shown on the plates completes the work. The plates are crude in their execution, but the magical name of Sowerby makes this volume extremely collectable.

### 15.3.99 Kurr

Johann Gottlob von Kurr was born January 15, 1798 at Sulzbach an der Murr,

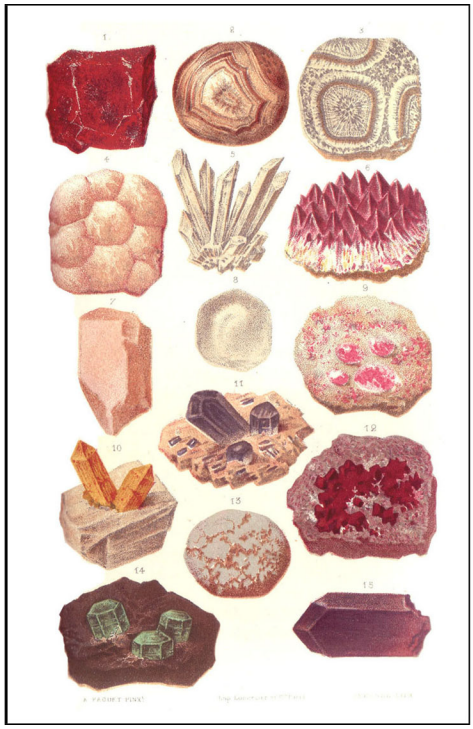
Germany. As a youth, he enjoyed a good education, which included terms at several schools. During the summer of 1828 he was asked to accompany an expedition to Norway to study and collect plants and minerals. Upon returning to Stuttgart, he was appointed professor of botany at the polytechnique school, eventually becoming a professor of mineralogy. During his lifetime, Kurr made many contributions, mostly mineralogical in nature, to the scientific journals of the day. Additionally, several books related to the earth sciences can be credited to him. Kurr died May 9, 1870.




Kurr, 1858

*Kurr's Das Mineralreich in Bildern* enjoyed great popularity from its first appearance in 1858. The text is divided into two sections. The first is an introduction to mineralogy, giving the usual details about hardness, specific gravity, etc. The second is a descriptive mineralogy that describes specific mineral species, many of which are then illustrated in figures on the plates. The attractive plates are what made this work so popular. They show mostly crystallized minerals and are so well executed that they were reissued time and again. Besides the numerous reissues of the original German edition and the several translations, which all contain the same plates either as hand colored lithographs or as chromolithographs, the plates were also used in Adolph Kenngott's Illustrierte Mineralogie which became the successor to Kurr's book.

### 15.3.99 Reynaud

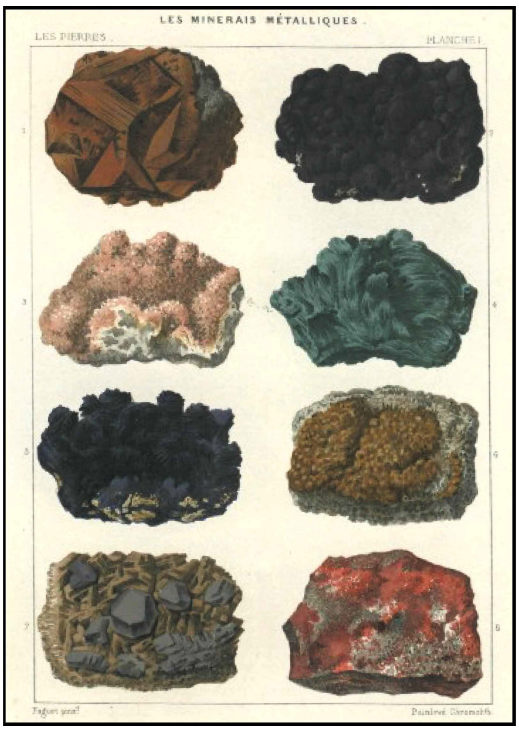


Reynaud, 1867

Jean Ernest Reynaud [1806-1836] published his *Histoire Élémentaire des Minéraux Usuels* and included two hand-colored plates. An apparently popular work in France intended to describe the economic minerals and containing two hand-colored plates of minerals specimens and crystals. Its authority in France is shown by the multiple editions that appeared over many years. It is written for the beginning student of mineralogy with its text covering stones, earths, fuels, mineral waters, precious

stones. The two colored plates are of mediocre quality.

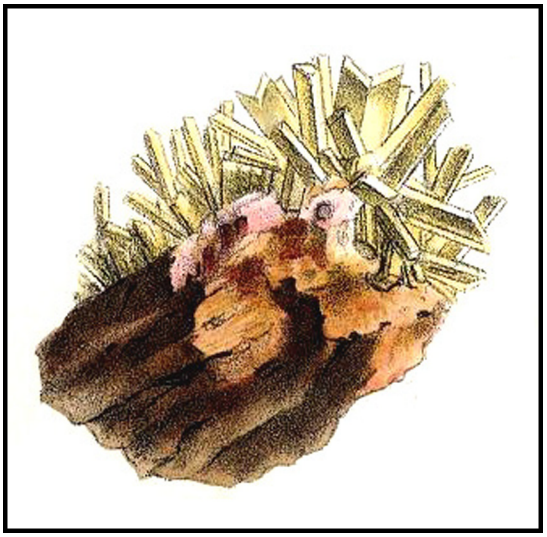
### 15.3.99 Simonin




Siminion, 1867

Louis Laurent Simonin [1830-1886] wrote *La Vie Souterraine, ou les Mines et les Mineurs* (1867) a profusely illustrated work on all aspects of mining. It is a comprehensive work on mining, which includes a history of mining, metallurgy and mineralogy, as well as methods, techniques and equipment. The three parts of the book are divided into coal-mining, metal-mining and the mining of precious stones. Simonin also includes sections on mining in America with a map of the sites along Lake Superior and one of California-Nevada. Perhaps the most notable part of this work is its attempt to represent mining life graphically. The many excellent text illustrations are engravings depicting mining techniques and conditions in the mines. A number of the illustrations show details of equipment ranging from drill bits to elevators to miner lamps. A long chapter discusses and pictures various mining accidents. Altogether a very interesting work of broad scope. There are accompanying the work ten chromolithographic plates heightened in gold and silver showing mineral specimens.

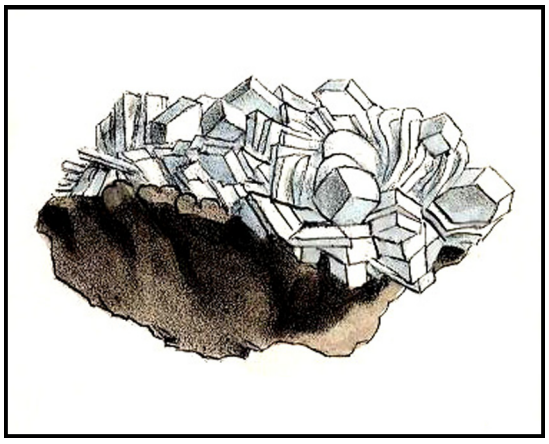
### 15.3.99 Weber



Weber, 1871 (Plate 4)

The *Die Mineralien in 64 colorirten Abbildungen* by Johann Carl Weber [1801-1875] is according to the title page, a second edition of the book. The work is also stated to have been improved by Karl Haushofer and has been enlarged to include those minerals found in the alpine regions. After a short introduction the described mineral species are arranged according to Kobell's *Mineralogie* (3rd ed., Leipzig, 1864). Each of these is then illustrated as one or two figures on one of the 64 chromolithographic plates that are scattered throughout the volume. These plates are apparently unique to the work and were not reproduced elsewhere; however, they are not depictions of the best quality and have an amateurish look about them.

According to the preface the first edition of this work appeared under the title, *Die Mineralien Baiern's und beschränkte sich auf Mineralien und Gesteine dieses Landes* (München, c1850), which described the minerals found in Bavaria. However, no copy of this book has been traced. Perhaps this first appearance was included as a section in some other unknown natural history work, or is



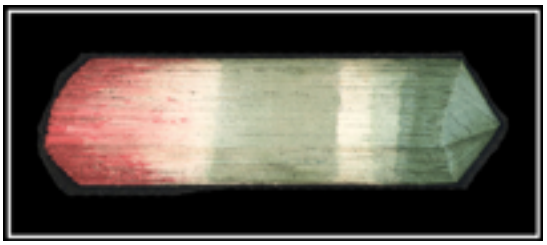
Weber, 1871 (Plate 2)

part of the unpublished two volume monograph *Abbildungen von Pflanzen, Insekten und Mineralien in München* cited by Nissen (BBI, no. 2120). In its second edition, *Die Mineralien in 64 colorirten Abbildungen* appears to be a companion volume to Weber's *Die Alpen-Pflanzen Deutschlands und der Schweiz in colorirten Abbildungen nach der Natur und in natürlicher Grösse* (3rd ed., München, 1872, 4 vols., 400 color illus.).

### 15.3.99 Hamlin

August Choate Hamlin [1829-1905] graduated from Bowdoin Colledge in 1851, immediately entering Harvard medical school, from which he received his M.D. in 1855. Afterwards he travelled to Paris where he continued his medical studies for two years. On the outbreak of America's civil war he raised a company of militia at his own expense. Afterward, he volunteered his services as a surgeon to the Second Maine Infantry. Throughout the war he was regularly promoted, becoming medical inspector of the army in 1864. With peace he returned to Bangor, Maine where he established a successful medical practice. Hamlin also had an active life in Maine politics which eventually brought about his appointment as Surgeon General of the state in 1882.

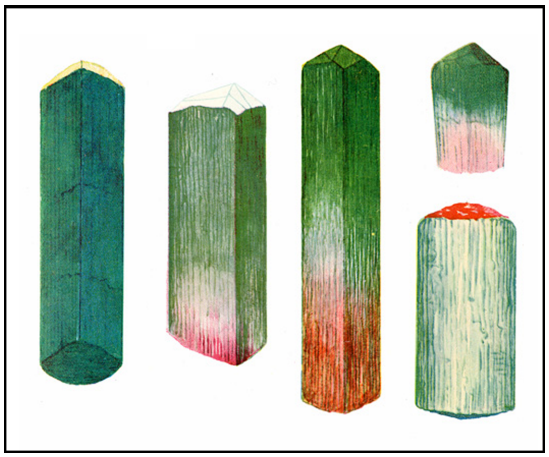
For pleasure Hamlin became a devoted scholar on two subjects, the Civil War and the tourmalines of Mount Mica, Maine. This pegmatite was discovered in 1820 by his father, Elijah L. Hamlin and was the object of many years of attention by the



Tourmaline (Hamlin, 1873)

Hamlin family. August Choate grew up admiring the tourmalines, and set his goal in life to collecting and preserving the best specimens. He wrote two very collectable books concerning these specimens. The first of these, *The Tourmaline* was published in 1873. This small volume begins with a general description of tourmaline, including its history, a derivation of its name, important worldwide occurrences, and descriptions its properties. One chapter describes the deposit at Mt. Mica. Of particular interest are the four chromolithographic plates showing several specimens of the Maine tourmaline. In 1895, Hamlin continued his tourmaline writings with *A History of Mount Mica*. This privately published volume chronicles the complete history of the deposit from the time of its discovery. It contains fascinating stories of early explorations, a description of the deposit, and diagrams showing where major pockets were found. There are also 43 chromolithographic plates illustrating many fine specimens of Mount Mica tourmaline. These illustrations along with Kunz's various works and Hamlin's earlier book are the finest mineral chromolithographs ever produced in the United States.

Dr. A. C. Hamlin [1828-1905] was a distinguished physician and businessman in Bangor, Maine. He served as Army Medical Inspector during the Civil War, later as Surgeon General of the State of Maine, and also as Mayor of Bangor from 1877 to 1878. In addition he was an ardent salmon fisherman, and a lover of gem minerals. He purchased the Mount Mica farm in Oxford County, Maine in order to mine the pegmatite there, and assembled the finest collection of its specimens known in the 1880's.



Tourmaline (Hamlin, 1895)

Hamlin, it appears, was also something of an artist. He made small watercolor paintings of many of his tourmaline crystals, and published them in two books about Maine tourmaline: The Tourmaline (1873) and The History of Mount Mica (1895). The originals of most of these paintings are preserved in the Harvard Mineralogical Museum. The is also a small chromolithograph of his painting of a Ceylon sapphire crystal from his collection in a third book of his: Leisure Hours Among the Gems (1891).

### 15.3.99 Kunz

George Frederick Kunz [1856-1932] wrote *Gems and Precious Stones of North America* (1890) a popular work that treats all aspects of gemology, especially the discovery of new gem deposits. This is Kunz's first major book and is devoted to a through description of North American gemstones. It contains information on gemstones and their locations in North America that Kunz had gathered from correspondents located all over the continent. These were the same people that supplied local information for inclusion in Kunz's annual contribution to the *Mineral Resources of the U.S.*, for which Kunz wrote the "precious stones" chapters for many years. In addition, being a vice president of the famous jewelry firm of Tiffany & Co., Kunz actively encouraged the exploitation of gem deposits and stood ready to purchase recovered material to financially assist such ventures. While much of the contained information has been augmented or improved upon in intervening years, the unique nature and value of this work is unquestioned and it is still of value today. Kunz included handsome colored lithographic plates to illustrate the best gem minerals of The United State, that together with those illustrations found in Hamlin's tourmaline monographs are among the very best chromolithographic renderings of minerals ever published in the United States.



Kunz (1890)

### 15.3.99 Brauns

Reinhard Anton Brauns was born at Eiterfeld, near Cassel, Germany, on August 20, 1861. His early schooling was spent at Marburg, where he attended the Gymnasium and the University. In 1894 he became professor of mineralogy and geology at the Technische Hochschule in Karlsruhe. A year later he was appointed to a similar position at Giessen, where he remained until 1904. Brauns was appointed to the University of Kiel where he stayed until 1907, when he took up the Professorship of Mineralogy and Petrography at the University of Bonn, which he would hold for the remainder of his life. Brauns died on January 28, 1937 as a result of a fractured skull he sustained upon being struck down by a streetcar.

Brauns was a prolific writer upon mineralogical subjects. Of his many books, including a well received textbook, was the last




Microcline (Brauns, 1903)

great chromolithographic mineralogy. In *Das Mineralreich* the plates are the chief attraction of the book as "the most important minerals are represented in their natural form, color, and size on 73 chromo-lithographic plates (preface)." The text is written in a popular style as the book was intended for a general audience. The images of the mineral specimens of the Braun's plates were a readily available source for other publishers, persumably with the permission of the original publisher. New plates that copy the Braun's specimen images appeared in the Czech language *Příroda A Její Divy Vi ... Minerály* (Prague, 1905) authored by Karel Kopecký and the Spanish *Atlas De Mineralogia* (Madrid, 1914) by Francisco Pardillo.

### 15.3.99 Sauer

In the first years of the twentieth century, the Stuttgart publisher Kosmos-Gesellschaft der Naturfreunde set about creating a set of chromolithographic plates showing fine, crystallized mineral speciemens. Using the earlier examples of Kurr and Brauns, their intention was to publish not only their own book, but to sell the plates and rights to publisher's in other countries so that they could print their own mineralogical work. To write the German text, Gustav Adolf Sauer [1852-1932] was engaged. He was at the time employed as a professor at the Technical High School of Stuttgart, but he later took a position in the geological survey of Baden and Württemberg, where he became the director. His book, *Mineralkunde als Einführung in die Lehre vom Stoff der Erdrinde* that although undated is known through contemporary notices to have been published in 1906, is the first work to contain the 26 color plates printed in 15 colors, depicting a substantial suite of mineral specimens, many of them quite fine. In this instance, the plates were rendered in superb chromolithographic examples.

The publishing rights to the mineral book and plates were then acquired by the Paris publishing house of Librairie Ch. Delagrave. There, a technician and chemistry assistant at the Sorbonne who prepared the chemical experiments used in the lectures at the University, F. Leteur was hired to write the French text. His book, *Traité Élémentaire de Minéralogie Pratique* , is like Sauer's undated, but is known from contemporary notices to have been printed in 1907. The Prague publishing firm of I.L. Kober also acquired rights, and published a Czech language version under the title *Atlas Minerálů* in 1907. Both of these versions also utilized the fine chromolithographic plates.

### 15.3.99 Spencer

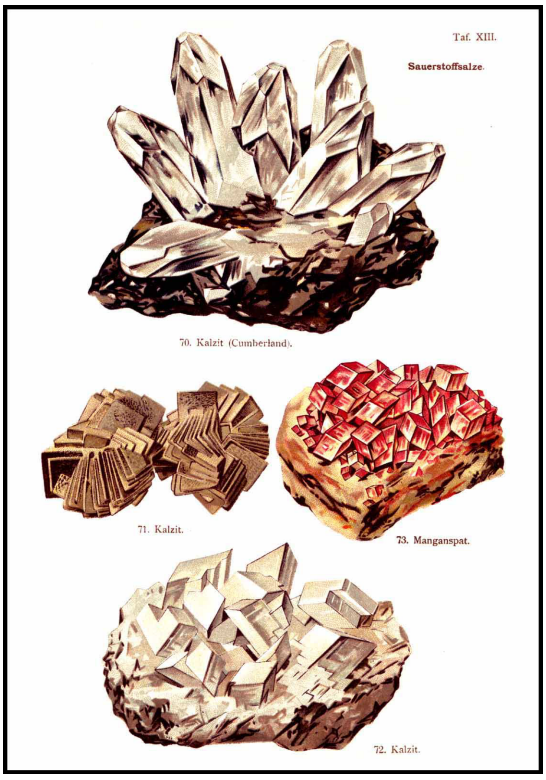
The famous English mineralogist Leonhard J. Spencer [1870-1959] had studied chemistry at the Royal College of Science in Dublin. He thereafter attended Cambridge where in his final year he won the Harkness Scholarship for the best paper in geology of his year. His ambition had been to join the Geological Survey of India; however, no post was available. Therefore, Spencer applied for and was accepted into a vacant mineralogist position at the British Museum (Natural History) that had occurred with the death of Thomas Davies [1837-1892]. He remained with the British Museum the remainder of his working

career, retiring finally in 1935. However, even in advanced age, he remained an active participant in geological and mineralogical activities. Notable among these was his adventure in 1934 at the age of 64 to investigate with P.A. Clayton the then unexplained deposit of almost pure natural silica glass in the Libyan Desert—this substance called "Libyan Glass" is now known to be of exterrestial origin. He was a longtime editor of the important mineralogical journals, *Mineralogical Magazine* and *Mineralogical Abstracts*. It is recorded that Spencer was active on his bibliographical work until a few days before his death. He was one of the best mineralogists of his generation, winning the Roebling Medal from the American Mineralogical Society in 1941 and being elected a Fellow of the Royal Society.




Spencer, 1911

Early in his career Spencer translated into English Reinhard Braun's famous mineralogical work, *The Mineral Kingdom* (London, 1908-1912). Although well received, this book was big and expensive, and out of the reach of most young readers. Spencer wanted to create a more economical book to encourage youngsters to take up mineralogy. This appeared in 1911 as *The World's Minerals* with 40 chromolithographic plates of fine crystallized mineral specimens. For the creation of these illustrations, Spencer contacted a friend of his, a German geologist by the name of Hans Lenk [1863-1938]. Lenk was at the time Professor of Mineralogy and Geology at Friedrich Alexander University of Erlangen-Nuremberg in Bavaria. In that capacity he was curator of the mineral collection, and so had a ready source from which to select mineral specimens to illustrate. In his preface, Spencer thanks Prof. Lenk for the forty colored plates that were created under his supervision, but whether this means Lenk created the illustrations or if they were farmed out to some unknown artist is unclear. They are never the less excellent renderings of crystallized specimens. In all 116 species of the more common simple minerals are illustrated in 163 figures.



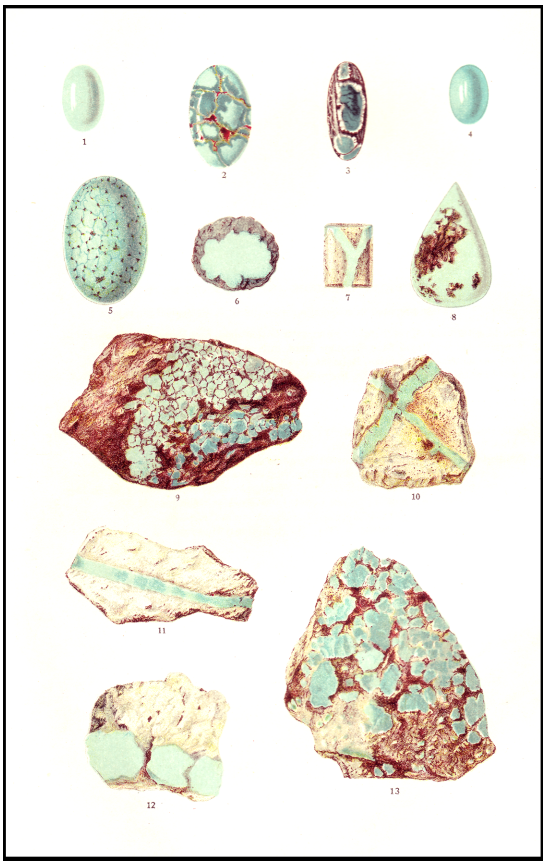

Schleyer, 1909

Like several other color mineral plates, the ones used by Spencer were not exclusive to his work. In fact they appeared first in August Schleyer's *Mineralogie* that was published in 1909. But in that book because of a larger page size the figures on the plates are in a different arrangement thus giving a total of 30 plates, and 170 mineral illustrations. These plates were reused when Schleyer's work was reissued in 1935, but the images were photographically produced.

It was through Spencer's work that the images are most commonly encountered. The American edition of Spencer's *The Mineral Kingdom* appeared in 1911 from the New York publisher Frederick A. Stokes. The rights to republish the images were also acquired by the Italian publisher Editore Libraio della Real Casa, and used in the *I Minerali* written by Ettore Artini, which was published in 1914, and many subsequent editions. These appearances were also in the chromolithographic examples. But it was probably the last time they were reproduced by this method. When they were reprinted in the 1916 New York edition of Spencer's book, they were converted to half-tone color plates. It was by this reproduction technique that these same plates were reproduced in Karl Schulz's *Mineralreich* (1923) and Chamber's *Mineralogical Dictionary* (1945).

### 15.3.99 Pogue

Joseph Ezekiel Pogue [1887-1971] was a geologist and mineralogist who took a great interest in the gem mineral turqoise. He compiled all he knew of the subject in his important *The Turquois. A Study Of Its History, Mineralogy, Geology, Ethnology, Archaeology, Mythology, Folklore, And Technology* (1915). It was published in the *Memoirs of the National Academy of Sciences*, **12**, part 2 (Washington 1915). in a volume of 206 pages, illustrated with 22 black and white photographs and a tipped in color frontispiece showing excellent reproductions of turquoise specimens. It is the most comprehensive and carefully researched book on its subject and is still referenced in modern scientific papers. It also contains an unparalleled bibliography of the subject.



Turquois (Pogue, 1915)

## 16.0 Petrology[1677]

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## 17.0 Meteoritics[1678]

**REWORK:** Though they are chiefly the concern of astronomers, meteorites, by their very nature, also interest mineralogists and geologists. They are, in effect, our only tangible messengers from interplanetary space, and their constitution supplies us with essential information about the history of our own planet.

From the earliest times man has been impressed by the fall of meteorites, not least because of their spectacular nature and their alleged fantastic properties. However, the scientific study of these objects was begun only in fairly recent times. Their extra-terrestrial origin was generally denied until 1794, when the German physicist Ernst Friedrich Chladni produced solid arguments in support of this view. However, some mineralogists remained sceptical even then. Laplace and Poisson considered meteorites to be the disjecta of lunar volcanoes, but changed their opinion when Biot published his conclusions on the 'Eagle' meteorite (Orne, 26th August 1803).

Many chemical and mineralogical analyses of meteorites were made in the course of the 19th century, particularly by Edward Howard (who was the first to demonstrate that all meteorites contain nickel), Berzelius, Wohler, Thomas Graham (who dis covered the presence of free hydrogen in meteoric iron), de Vauquelin and Laugier (who discovered the presence of chromium), Dufrenoy, Boussingault, Damour and Pisani. Daubree proposed a system of classification based on the relative presence of ferro-nickel and silicates, and performed interesting experiments (1866) on the structure and genesis of meteorites. Noting the absence in meteorites of stratified rocks and granite, he introduced the concept of a 'universal scoria' represented by peridot or olivine (Mg, Fe) ZSiO4, both in ultrabasic rocks and also in meteorites. Finally, he suggested that those bodies from which the meteorites had originally split off must consist of concentric layers and that their density must increase from the surface to the centre, where only iron and nickel are found.

Though the spectrum analysis of the light emitted by the stars gives us reliable information about their chemical constitution, all our direct knowledge of extra-terrestrial matter is based on the examina tion of meteorites. Since Daubree published his system of classification in the 19th century which has been retained with minor modifica tions, much work has been done on the constitution of meteorites, on cosmic dust, on the nature and proportion of the isotopes contained in them and on their radioactivity. These studies have provided a great deal of new information on the population, age, and mode of formation of the solar and stellar systems.

Meteorites are on display in most important natural history museums. The catalogue published by G. T. Prior and Max. H. Hey lists all the known falls of meteorites before 1953; falls since then have been recorded by - the Permanent Meteorite Committee, an inter national body established in 1948. The study of meteorites is increas ing with space research projects, and may be regarded as an extension of geochemistry into space.

## 18.0 Study of Caves[1679]

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